TRANSMISSION LINE CONSTANTS

FOR

CORONA LIMIT
CORONA LOSS
CHARGING CURRENT
CHARGING KVA

By

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CHARGING CURRENT AND CHARGING KVA

In the determination of the electrical characteristics of a transmission line the corona limit, corona loss, charging current and charging KVA are of considerable significance. Frequently one or more of these items are of major importance. Fortunately, these factors are practically independent of the conductor material. This fact permits a graphical presentation of these data based upon conductor diameter and which is applicable to copper, aluminum, steel and any combinations of these or other metals.

The curves in this paper are prepared on the basis of conductor diameter and for various spacings. All voltages are line to line voltages and corrections for temperature are in Fahrenheit degrees.

CORONA LIMIT

Many experiments and tests have been made to determine corona effects and the maximum voltage at which conductors can be successfully operated. The results are still incomplete and the formulae that have been evolved are approximate only. A formula that was developed by F. W. Peek, Jr. formerly with the General Electric Company has been widely used for voltages up to 220 KV for thirty years and has given excellent results. Peek's formula for the disruptive critical voltage is as follows:

$$E_0 = 21.1 M_0 R \delta \quad \mathrm{LOG}_E \frac{S}{R}$$

where E_0 is the voltage at which corona loss starts in fair weather and is the corona limit voltage in KV to neutral, M_0 is the rougnness or irregularity factor depending on the surface and shape of the conductor, R the radius of the conductor in centimeters, S the spacing of the conductors in centimeters and δ the air density correction factor.

The Corona Limit Curves, Curve Sheets Nos. 1-6 were calculated from the above formula modified so as to be applicable to English units and line to line voltages.

The roughness or irregularity factor has been taken as .93 for solid or tubular conductor, .87 for stranded cable, 6/1 or more strands and .78 for 3 strand conductor.

The Fair-Weather Corona Limits in KV are for line to line voltage and are the voltages at which corona loss starts in fair weather. These curves are for 60 cycle or other commercial frequencies, equilateral spacing, sea level (barometer 29.92 inches) and 77 degrees Fahrenheit. The adjustment for altitudes other than sea level and temperatures other than 77 F. are shown on Air Density Correction Curve, Curve Sheet No. 7. Some investigations indicate that 2/3 of the conductor rise above ambient should be added to the ambient temperature of the air in using the temperature correction factor.

For flat spacing whether horizontal or vertical the Corona Limit KV should be multiplied by 96% for the center conductor and multiplied by 106% for the two outside conductors.

Practice has been to design transmission lines so that they would not be operated in excess of the Fair-weather Corona limit KV. The Corona Limit KV for wet weather is approximately 80% of Fair-weather values.

Investigations by William S. Peterson of the Department of Water and Power of the City of Los Angeles indicate that Peek's formulae do not give accurate results for conductors with diameters greater than 1 inch, that is, for conductors larger than those covered by the curves relating to corona in this paper.

CORONA LOSS

Peek's formula for P the power loss due to corona is as follows:

$$P = \frac{390}{\delta}(F + 25)\sqrt{\frac{R}{S}}\,(E - E_0)^2 \times 10^{-5}$$

This formula gives the power loss in KW per conductor per mile where F is the frequency and E is the line to neutral voltage in KV. It will be noted that corona loss occurs only when the applied voltage exceeds the corona limit voltage. The frequency was taken as 60 cycles and the formula modified so as to be applicable to line to line voltages. The values of:

$$\frac{390\,(60 + 25)\sqrt{\frac{R}{S}}}{3 \times 10^5}$$

were calculated as the Corona Constant and plotted for various diameters and spacings on the Corona Loss Curve, Curve Sheet No. 8. The following formula:

$$\text{KW CORONA LOSS} = \frac{\text{CORONA CONSTANT (APPLIED KV} - \text{CORONA LIMIT KV)}^2}{\text{AIR DENSITY CORRECTION FACTOR}}$$

gives the corona loss in KW per conductor per mile. The Applied KV and Corona Limit KV are line to line voltages. The Corona Limit KV is obtained from the Curve Sheets Nos. 1 - 6 modified by the Air Density Correction Factor as determined from Curve Sheet No. 7. For equilateral spacing the total line loss per mile is 3 times the loss per conductor per mile.

For flat spacing either horizontal or vertical the Corona Limit KV as obtained from Curve Sheets Nos. 1-6 and adjusted in accordance with Curve Sheet No. 7 should be multiplied by 96% to obtain the Corona Limit KV of the center conductor and by 106% for the Corona Limit KV of an outside conductor and these values of Corona Limit KV when substituted in the above KW Corona Loss formula will give the respective losses per mile for the center conductor and an outside conductor. For flat spacing the total line loss per mile is found by adding the loss per mile of the center conductor to 2 times the loss per mile of an outside conductor.

In order to determine the corona loss in foul or wet weather the Corona Limit KV as shown on Curve Sheets Nos. 1-6 is multiplied by 80% and after adjustment for altitude and temperature this reduced value of Corona Limit KV is substituted in the KW Corona Loss formula and the loss per mile per conductor and per mile of line is calculated in the same manner as outlined for fair weather conditions.

For conductors from .7 to 1 inch in diameter it is likely that the more detailed empirical method of Carrol and Rockwell of Stanford University will give more accurate results for the conductors which it covers than Peek's formulae.

CHARGING CURRENT

The Charging Current Curves for single phase line, Curve Sheet No. 9 where I is the charging current was calculated from the formula:

$$I = \frac{1}{2} E \frac{2 \pi F \times 38.83 \times 10^{-9}}{\log_{10} \frac{S}{R}}$$

The charging current formula for equilateral spacing where I is the charging current per conductor and E the voltage to neutral,

$$I = E\,\frac{2\pi F \times 38.83 \times 10^{-9}}{\mathrm{LOG}_{10}\frac{S}{R}}$$

was used in making the calculations for the Charging Current Curves for 3 phase equilateral spacing, Curve Sheets No. 10-20, except as modified so as to be applicable to line to line voltages.

The charging current formula for flat spacing, either vertical or horizontal, where I is the equivalent charging current per conductor, E the voltage to neutral and A the distance between adjacent conductors,

$$I = \frac{2\pi F \times 38.83 \times 10^{-9}}{\mathrm{LOG}_{10}\frac{1.26A}{R}}$$

was used in making the calculations for the Charging Current Curves for 3 phase flat spacing, Curve Sheets No. 21-31 except as modified so as to be applicable to line to line voltages. In a line without transpositions the charging current in the middle conductor will differ from that in the outside conductors. The current indicated by the Charging Current Curves for flat spacing are correct only for lines that are transposed at regular intervals. However, the equivalent charging current may be used for calculating voltage rise for lines with no transpositions or lines transposed at regular intervals.

The above charging current formulae do not take into account the effect of the line capacitance to earth as this effect is slight.

CHARGING KVA

The Charging KVA Curves, Curve Sheets No. 32 - 54 are based on the preceding charging currents. Line transposition or absence of transpositions have no effect on the accuracy of the Charging KVA Curves.

COPPER EQUIVALENT

The curve of Copper Equivalent Based Upon Resistance affords a ready means of determining the copper equivalent of various types of conductors.

References:

Dielectric Phenomena in High Voltage Engineering,
F. W. Peek, Jr., Third Edition, 1929.

Standard Handbook for Electrical Engineers,
Seventh Edition, 1941.

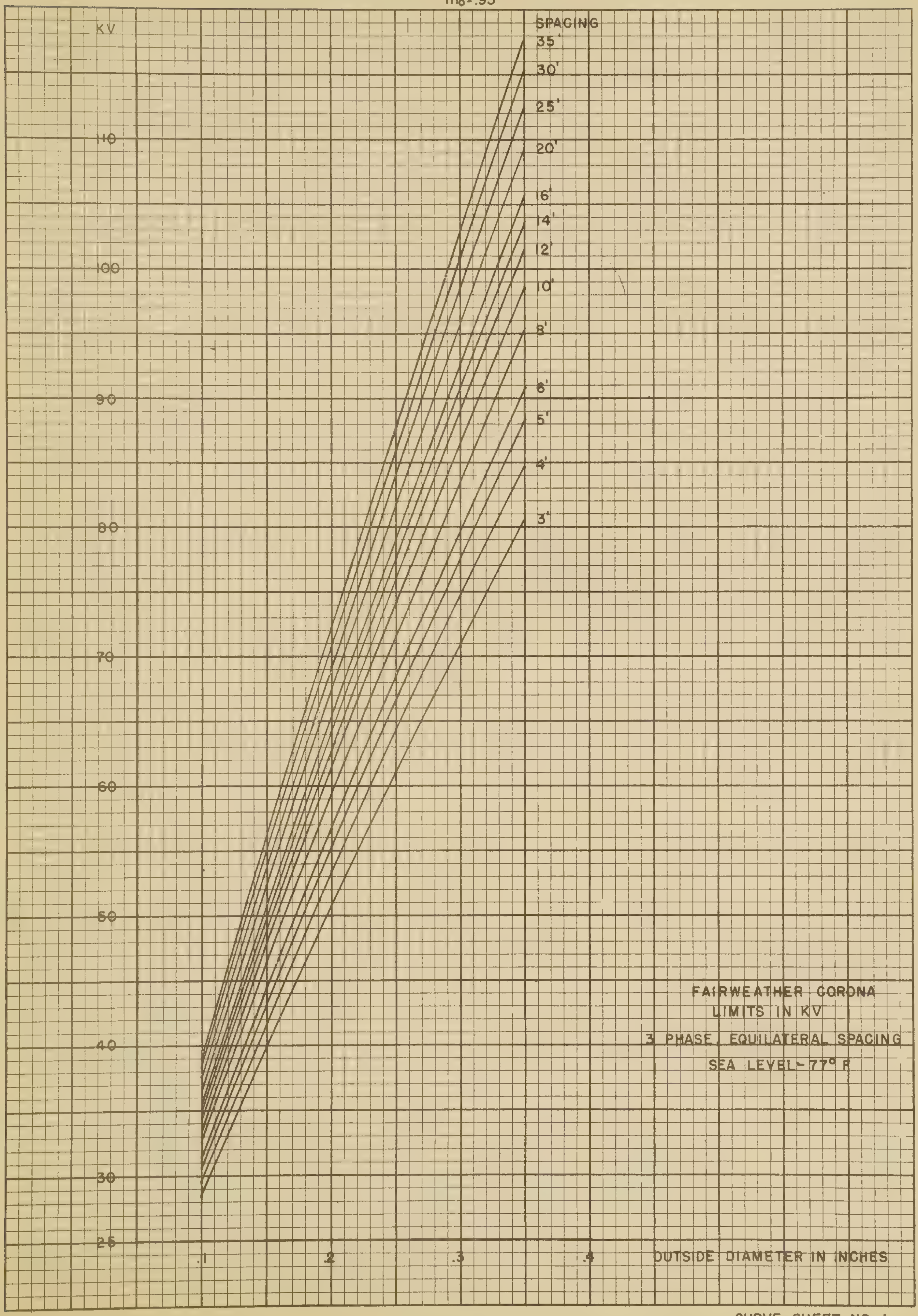
Transactions American Institute of Electrical Engineers, 1933,
Vol. 52, Page 62.

Transactions American Institute of Electrical Engineers, 1937,
Vol. 56, Page 558.

Transmission Line Formulas, Herbert B. Dwight,
Second Edition, 1925.

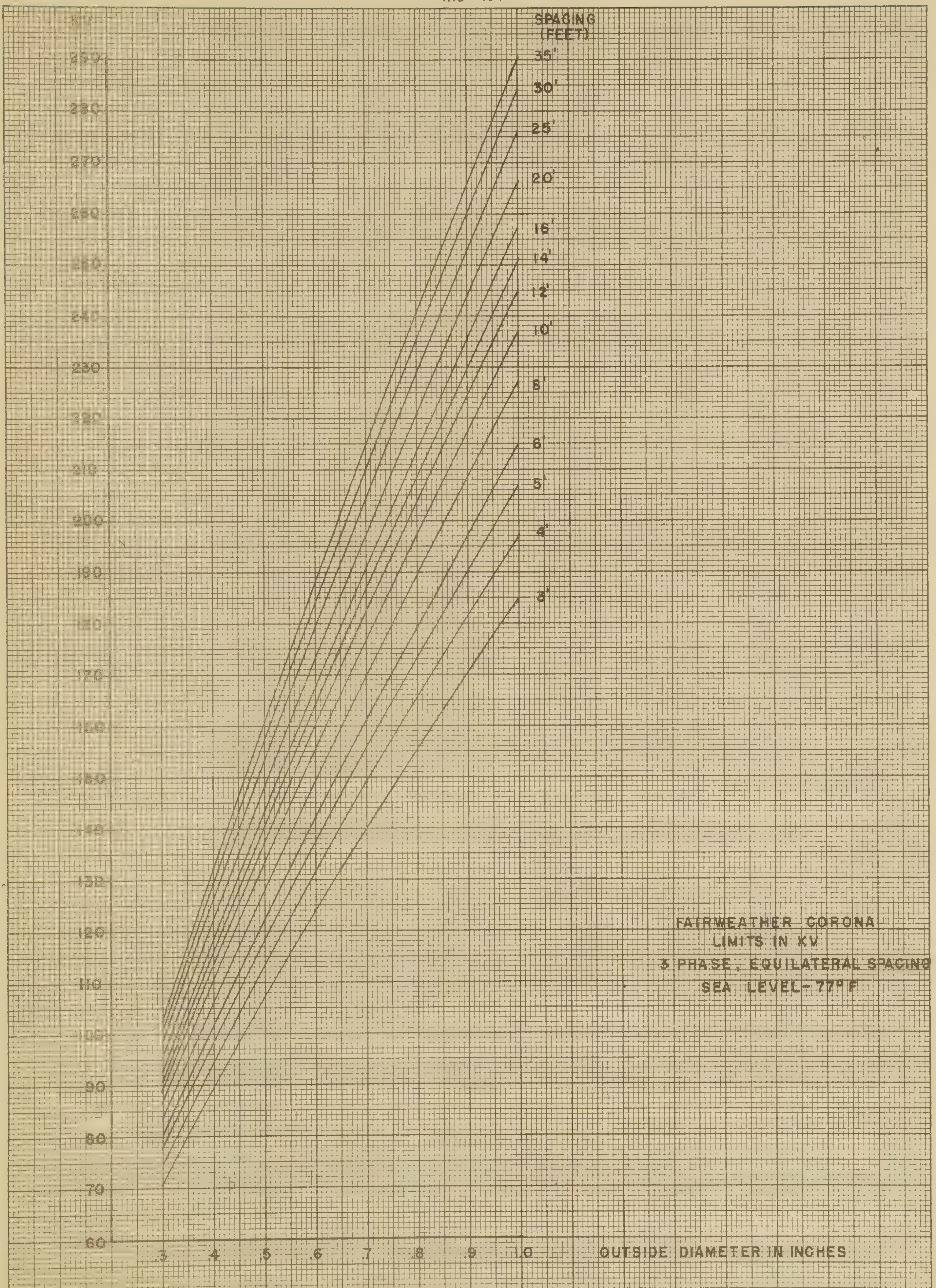
SOLID OR TUBULAR CONDUCTOR

$m_0 = .93$



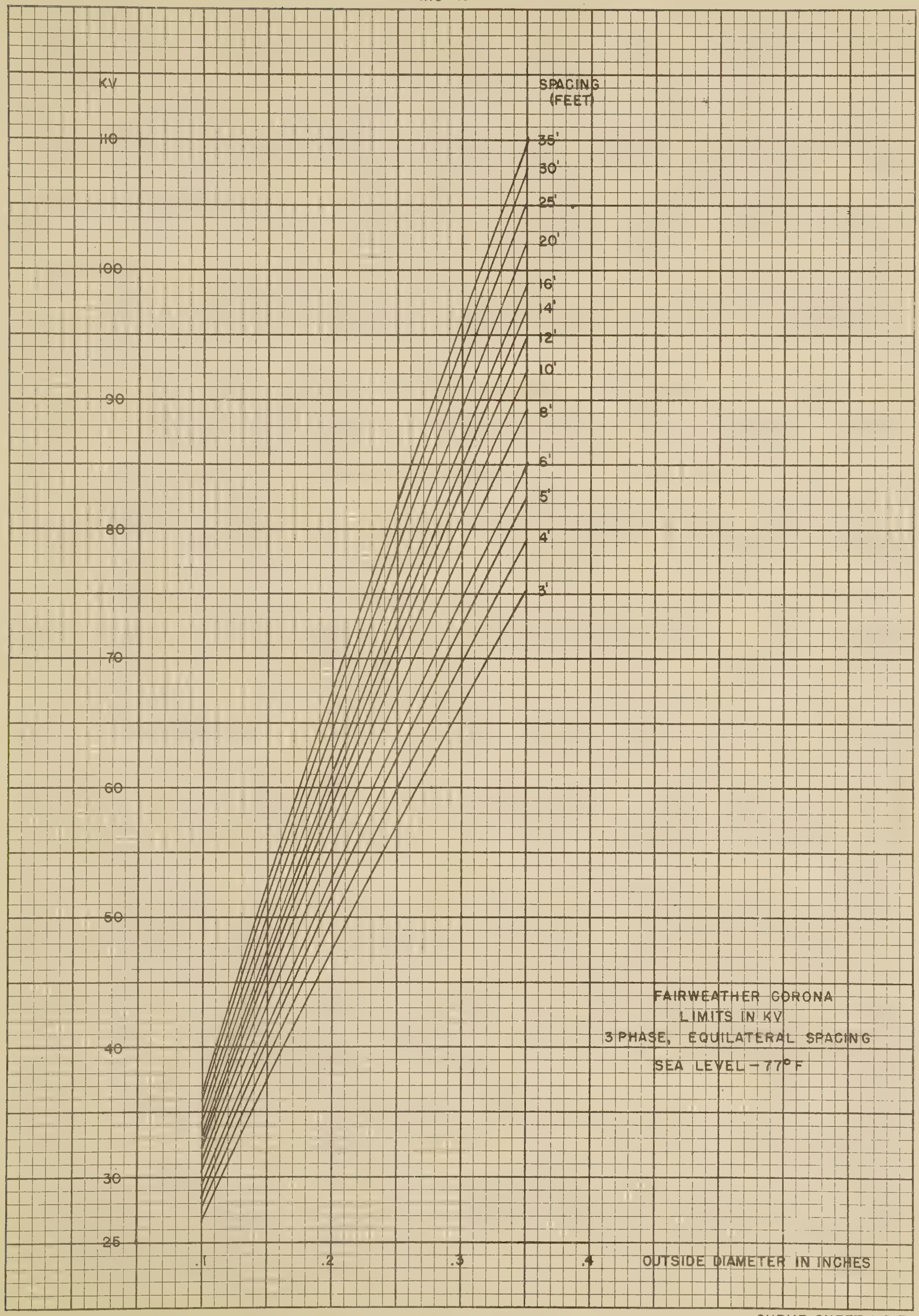
CURVE SHEET NO. 1

SOLID OR TUBULAR CONDUCTOR
$m_o = .93$

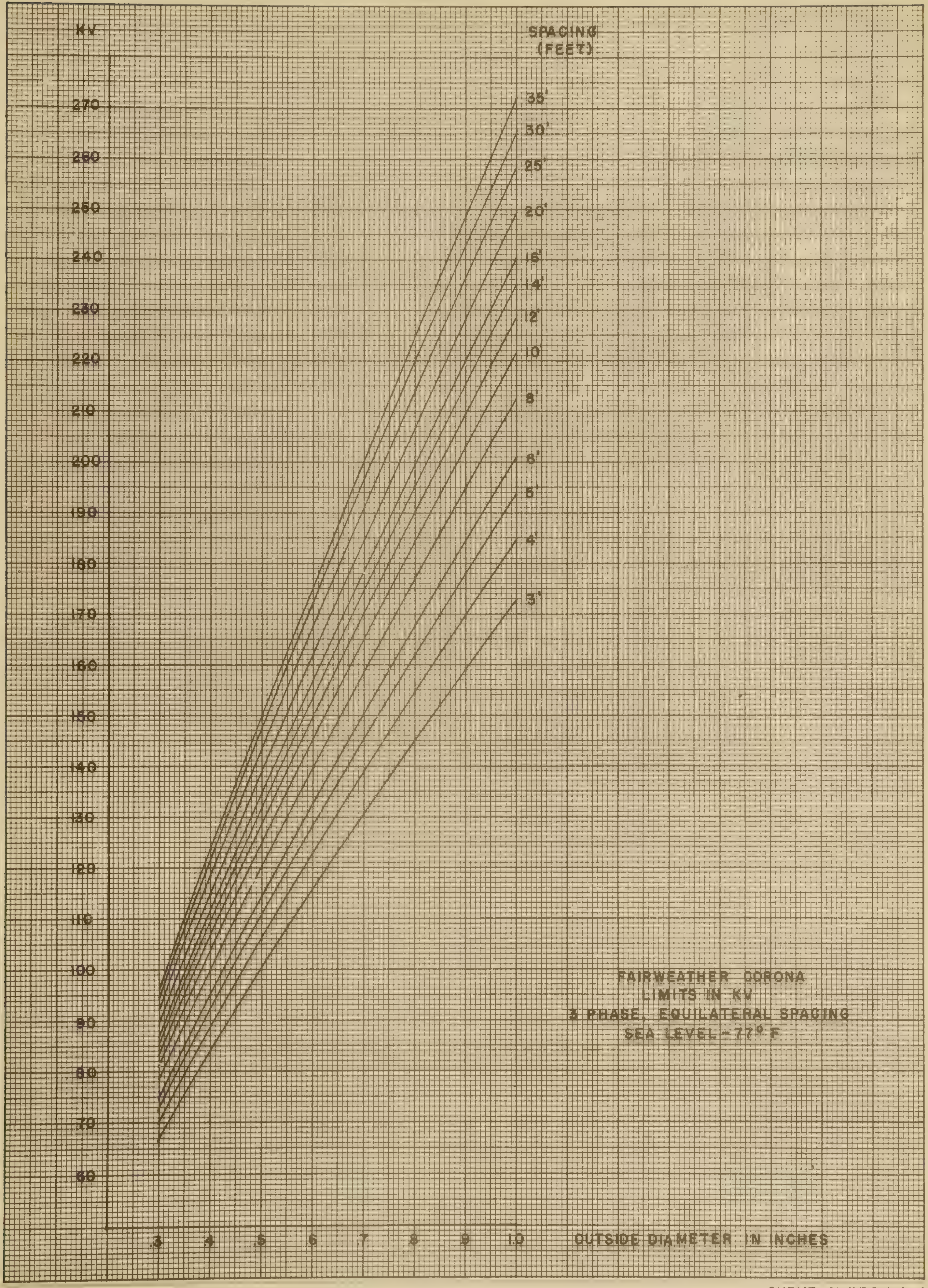


CURVE SHEET NO. 2

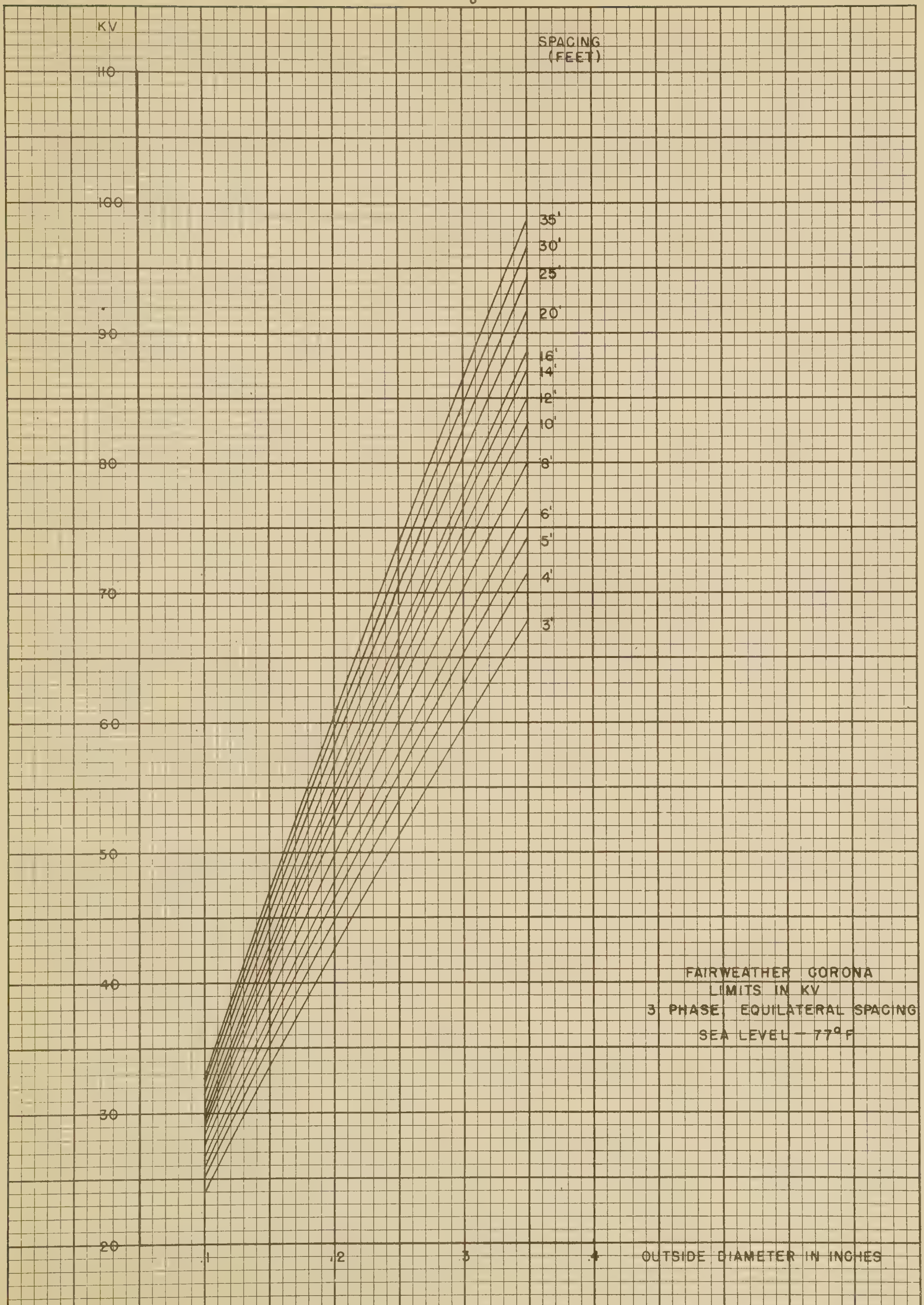
CABLE — 7 OR MORE STRANDS
$m_o = .87$



CABLE — 7 OR MORE STRANDS
$m_o = .87$

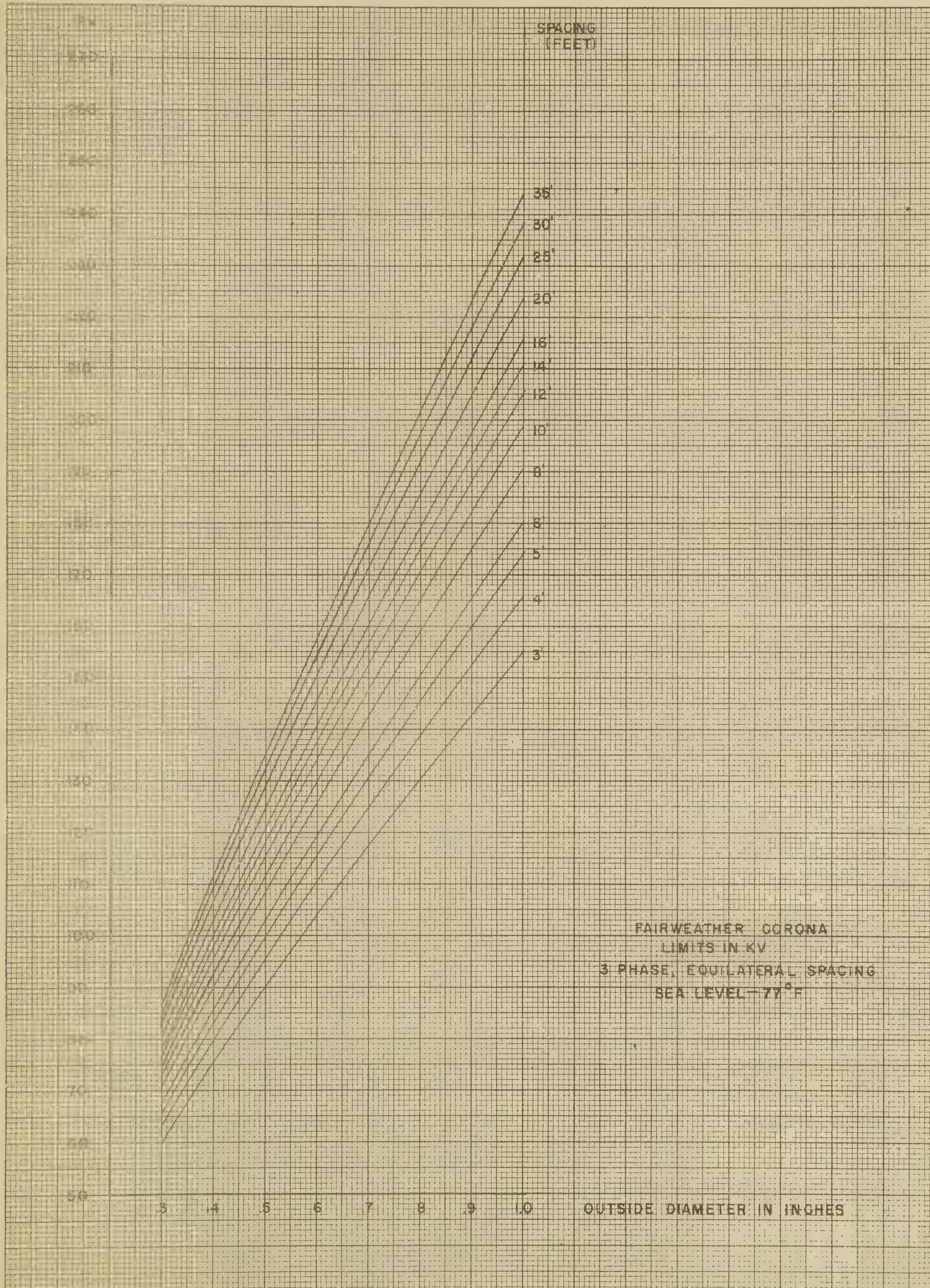


3 STRAND CONDUCTOR
$m_o = .78$

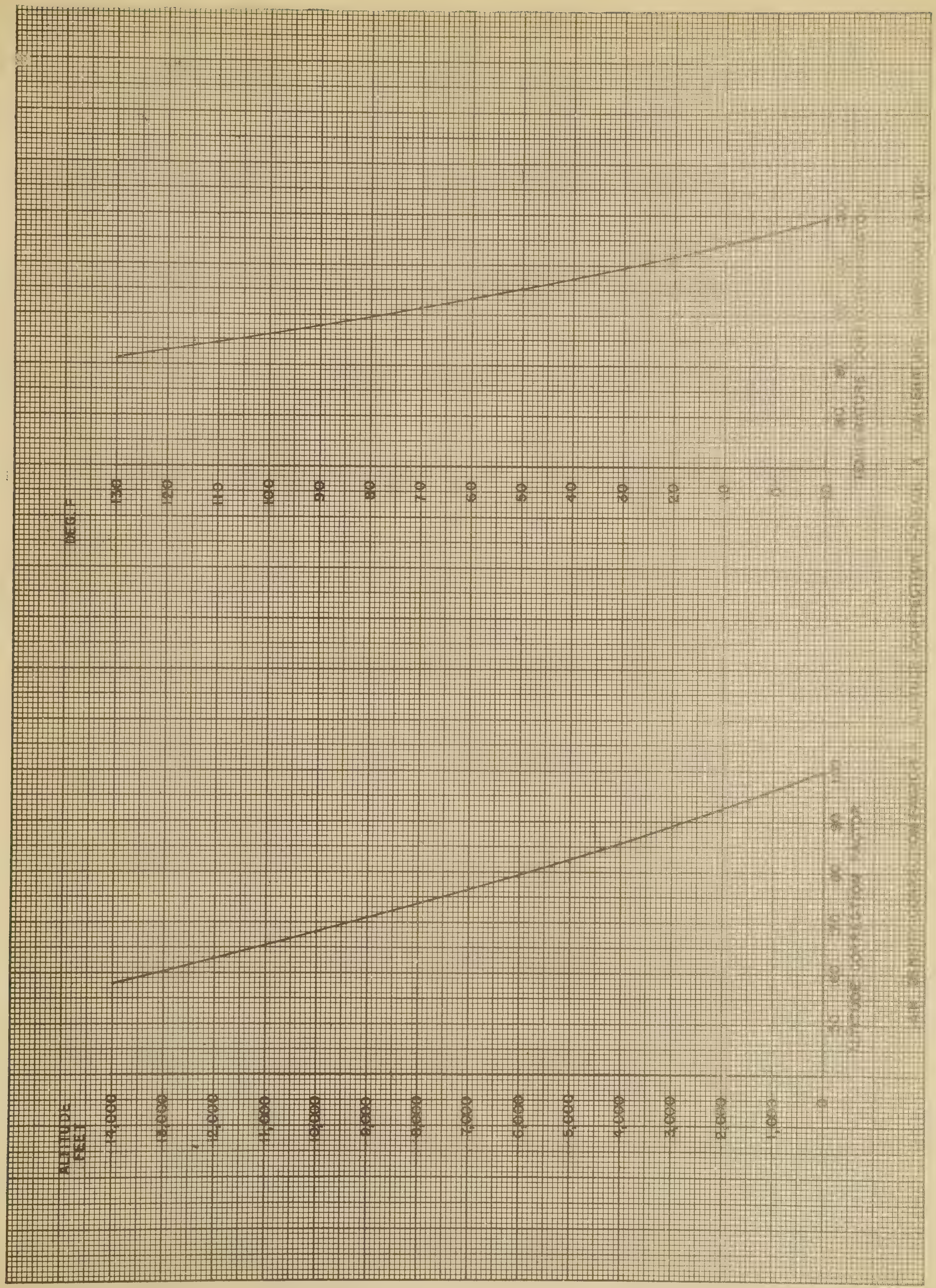


CURVE SHEET NO. 5

3 STRAND CONDUCTOR
$m_o = .78$

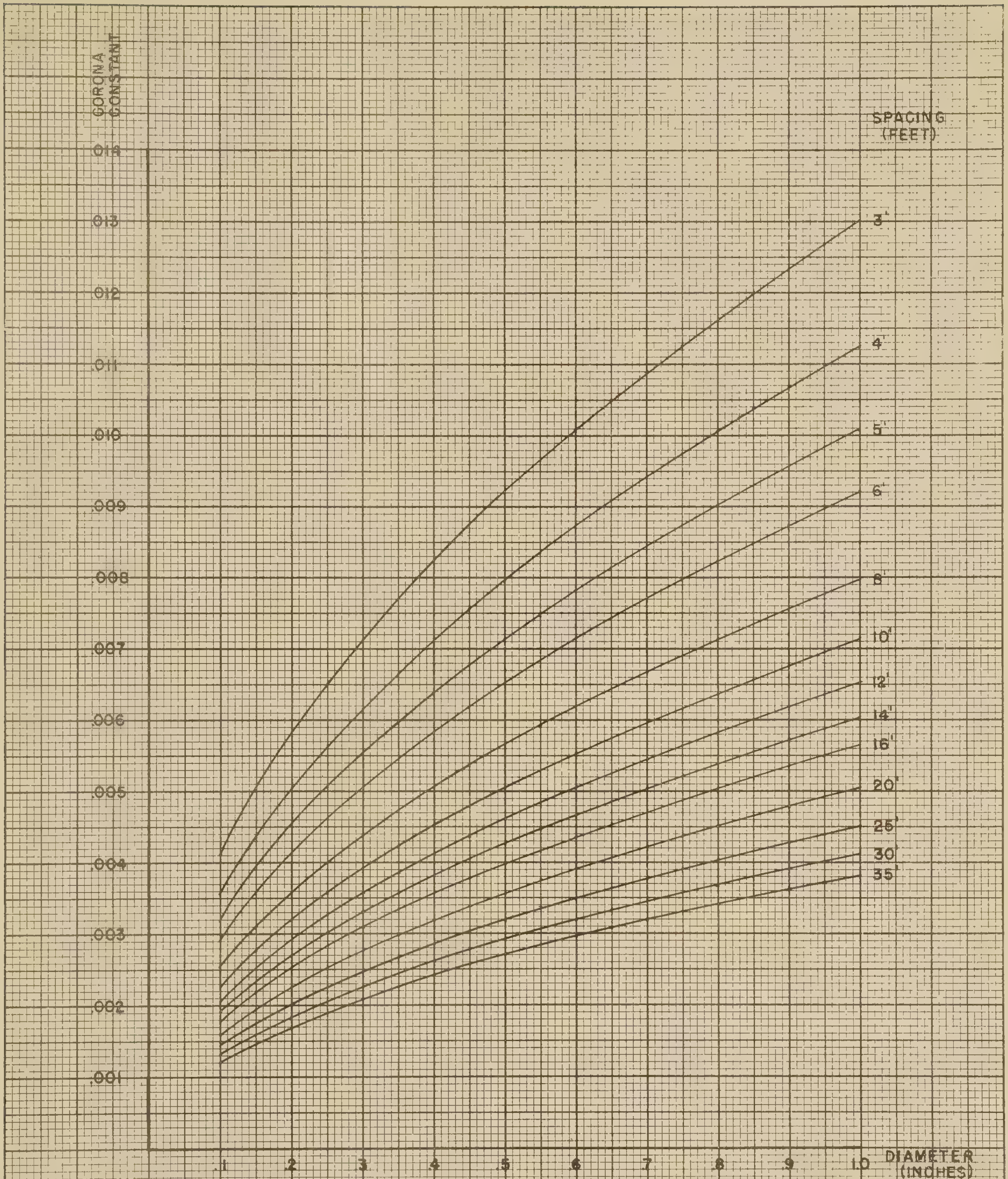


CURVE SHEET NO. 6



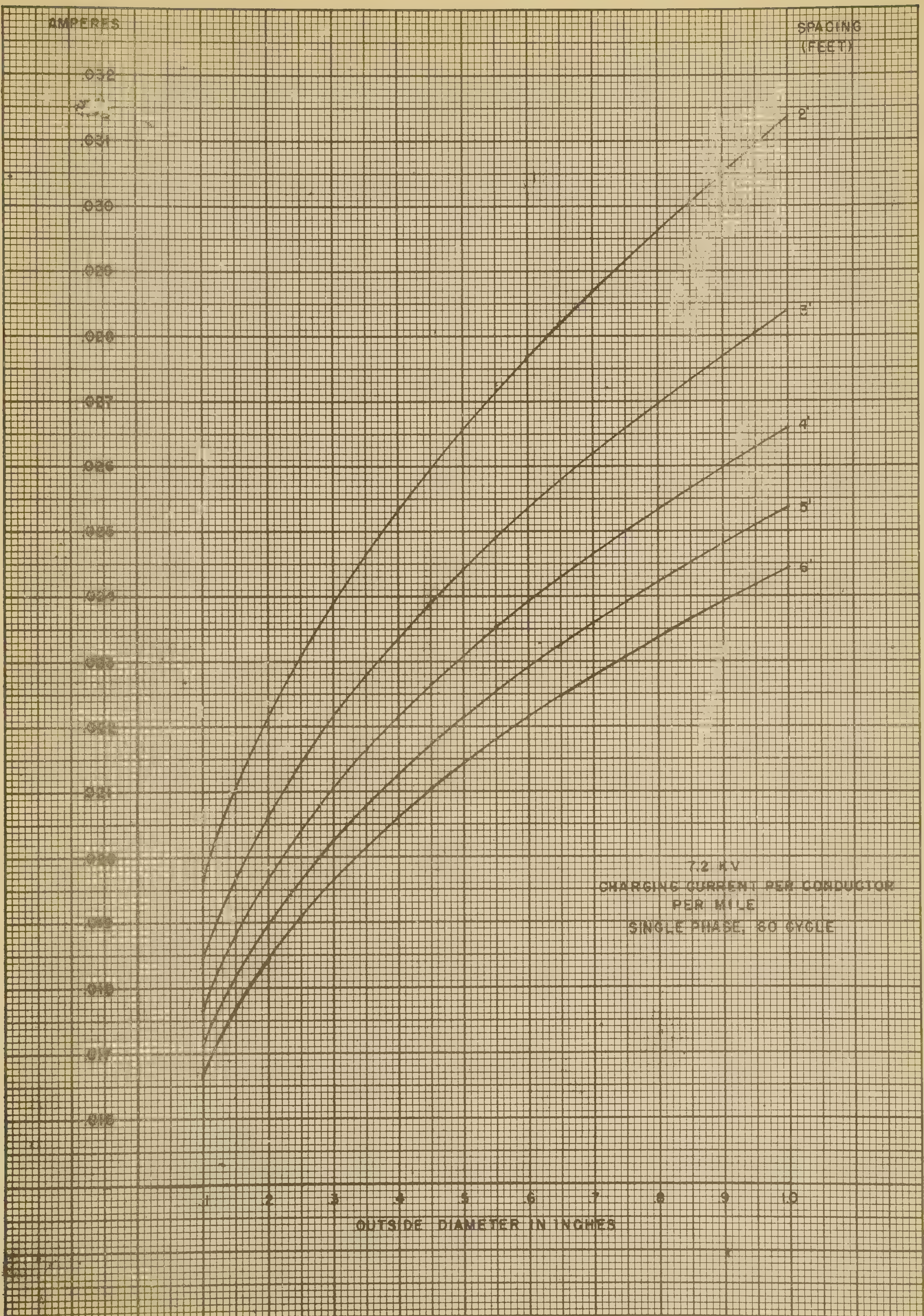
CURVE SHEET NO. 7

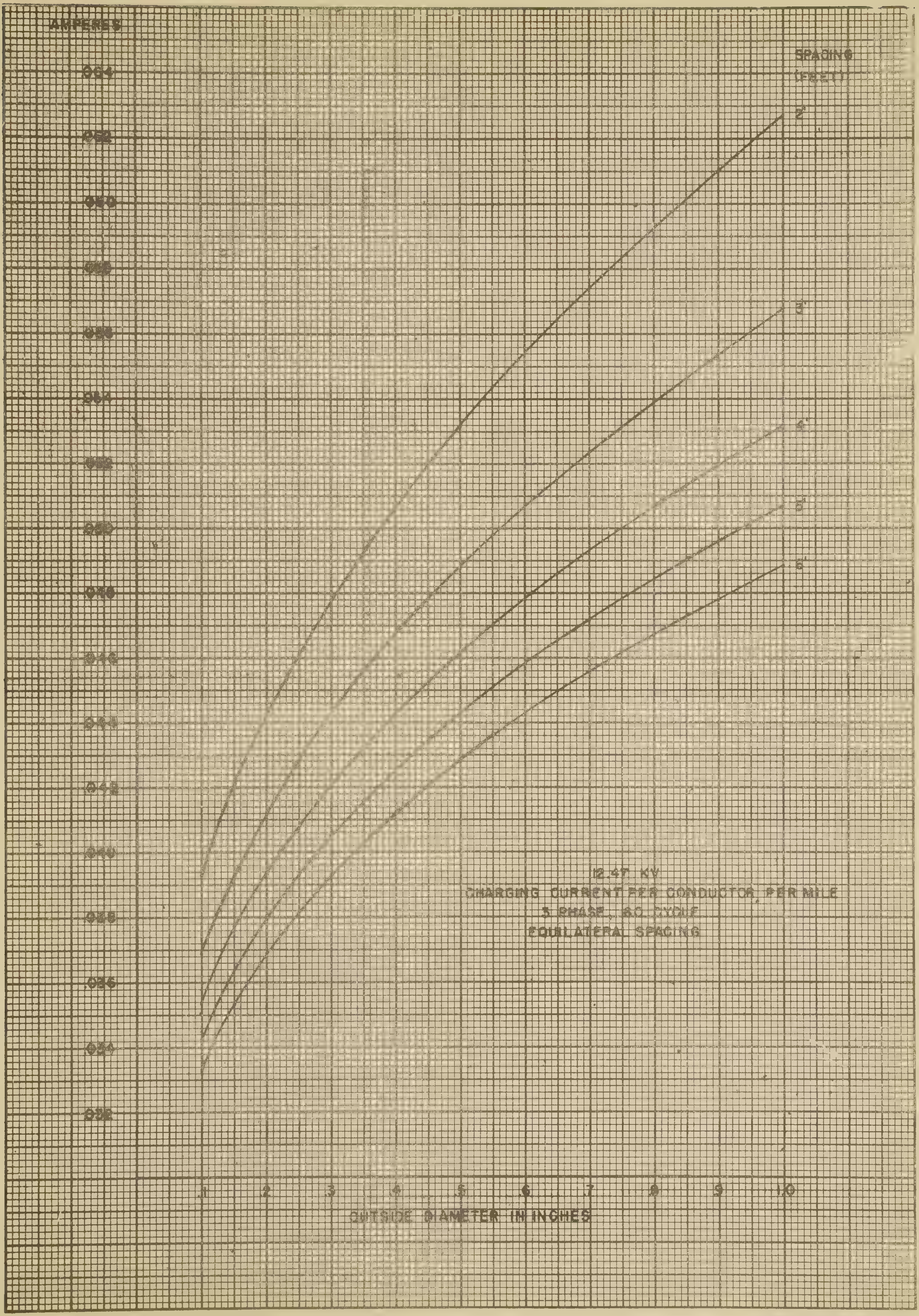
CORONA LOSS
60 CYCLE



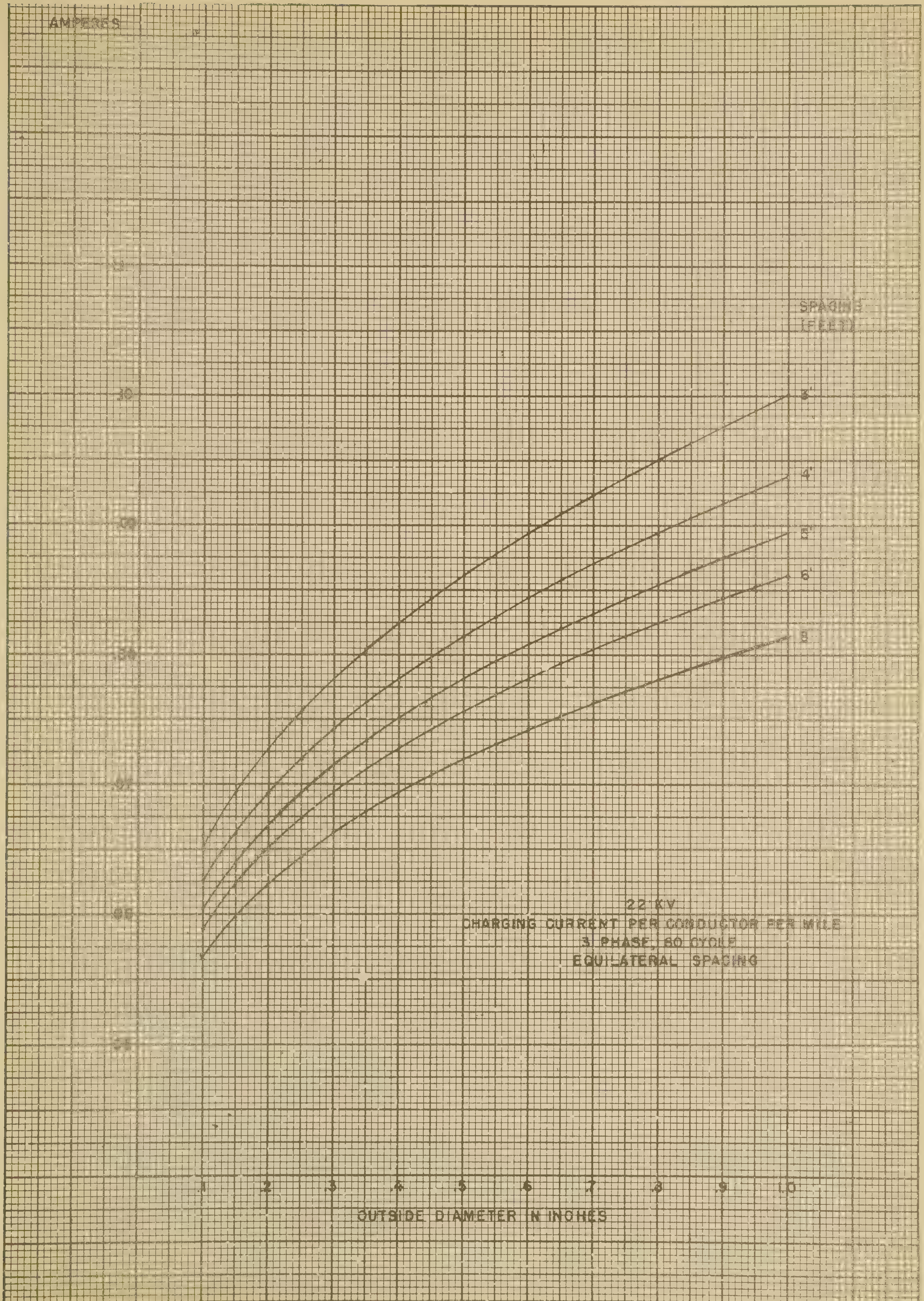
$$\text{KW CORONA LOSS}^{*} = \frac{\text{CORONA CONSTANT (APPLIED KV}^{**} - \text{CORONA LIMIT KV}^{**})^{2}}{\text{AIR DENSITY CORRECTION FACTOR}}$$

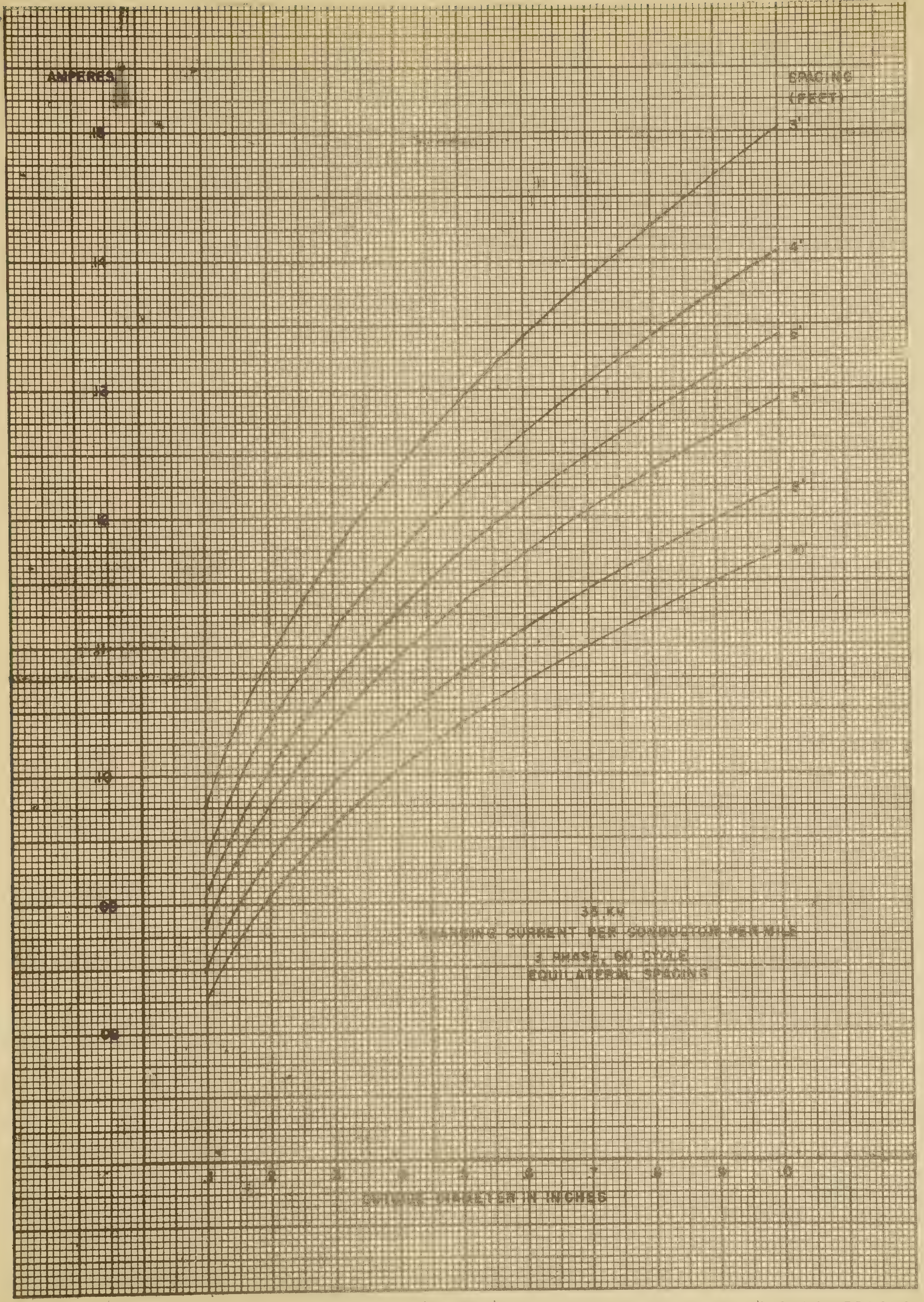
* PER MILE PER CONDUCTOR
** LINE TO LINE VOLTAGE


AMPERES
SPACING (FEET)
.032
.031
.030
.029
.028
.027
.026
.025
.024
.023
.022
.021
.020
.019
.018
.017
.016
2'
3'
4'
5'
6'
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
OUTSIDE DIAMETER IN INCHES
7.2 KV
CHARGING CURRENT PER CONDUCTOR
PER MILE
SINGLE PHASE, 60 CYCLE

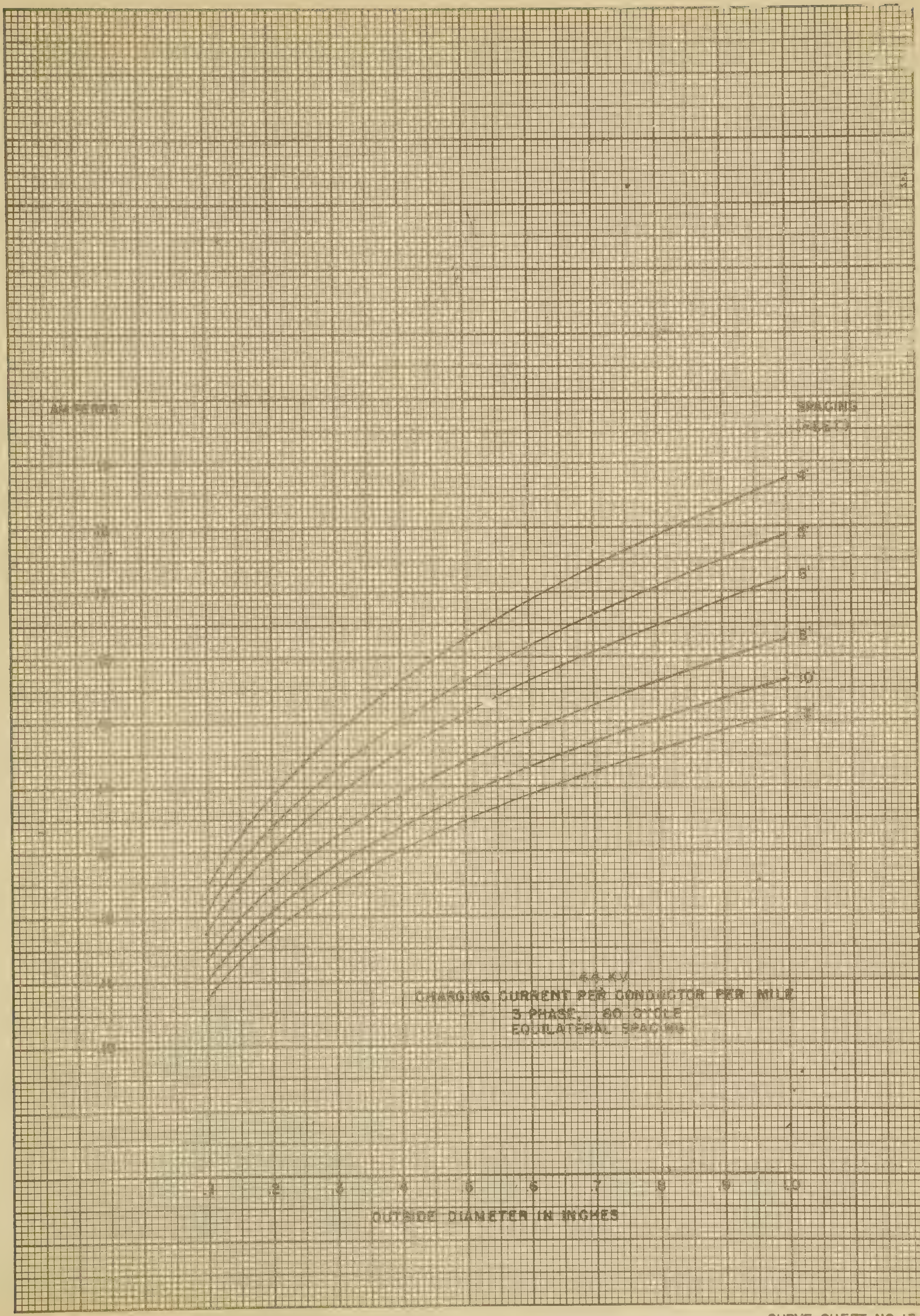


CURVE SHEET NO. 10


AMPERES
.10
SPACING
(FEET)
3'
4'
5'
6'
8'
22 KV
CHARGING CURRENT PER CONDUCTOR PER MILE
3 PHASE, 60 CYCLE
EQUILATERAL SPACING
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
OUTSIDE DIAMETER IN INCHES



CURVE SHEET NO. 12



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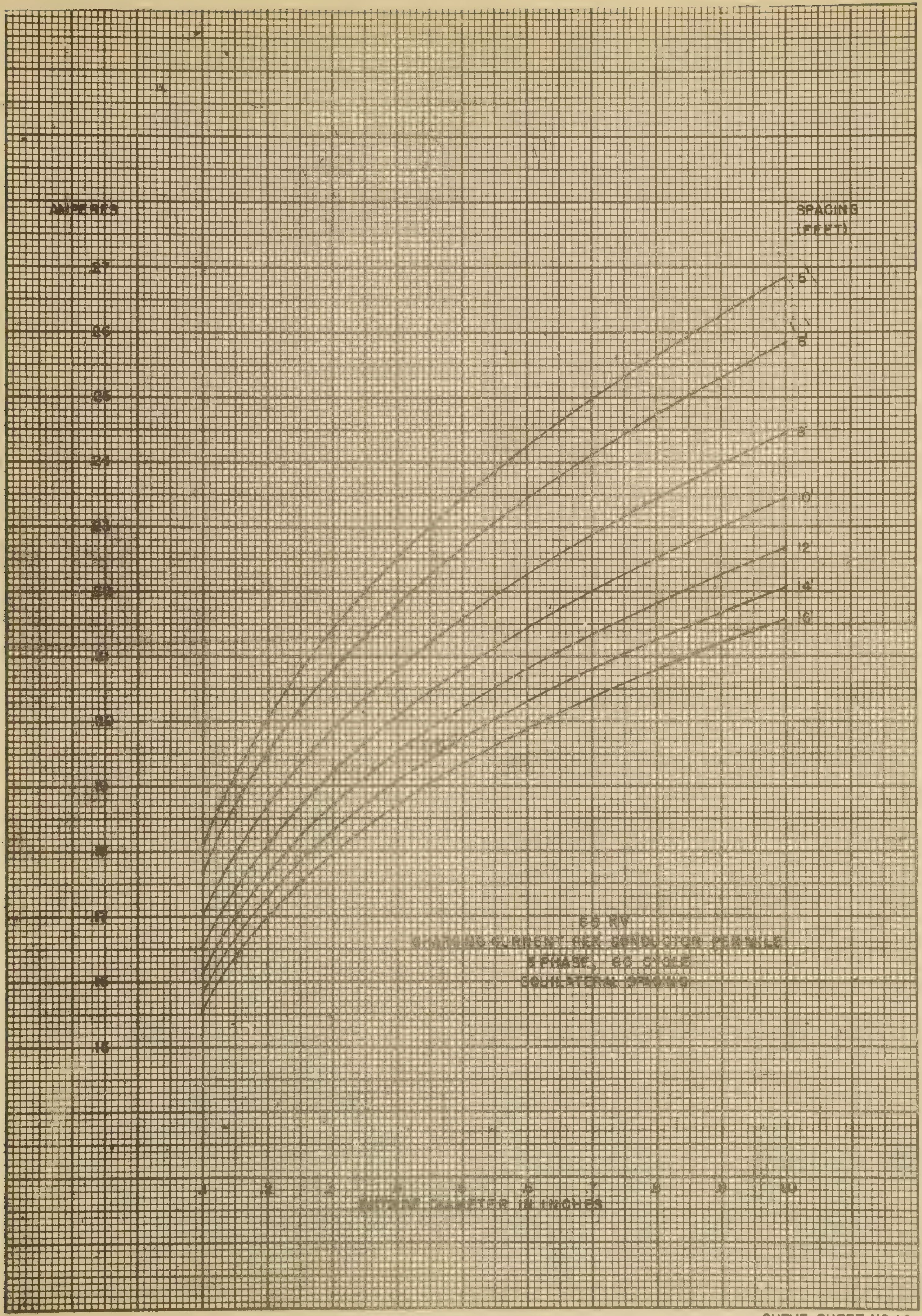
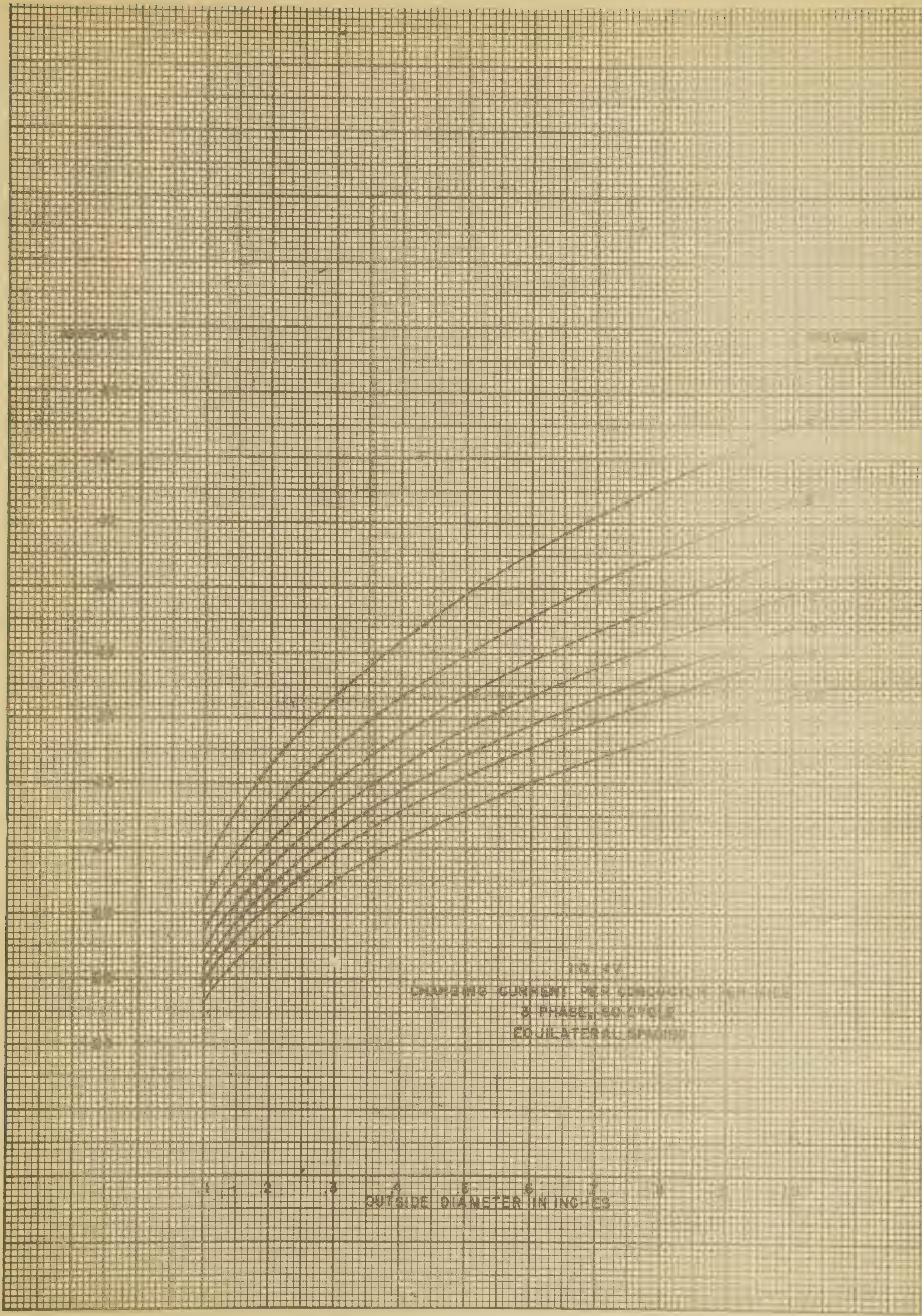
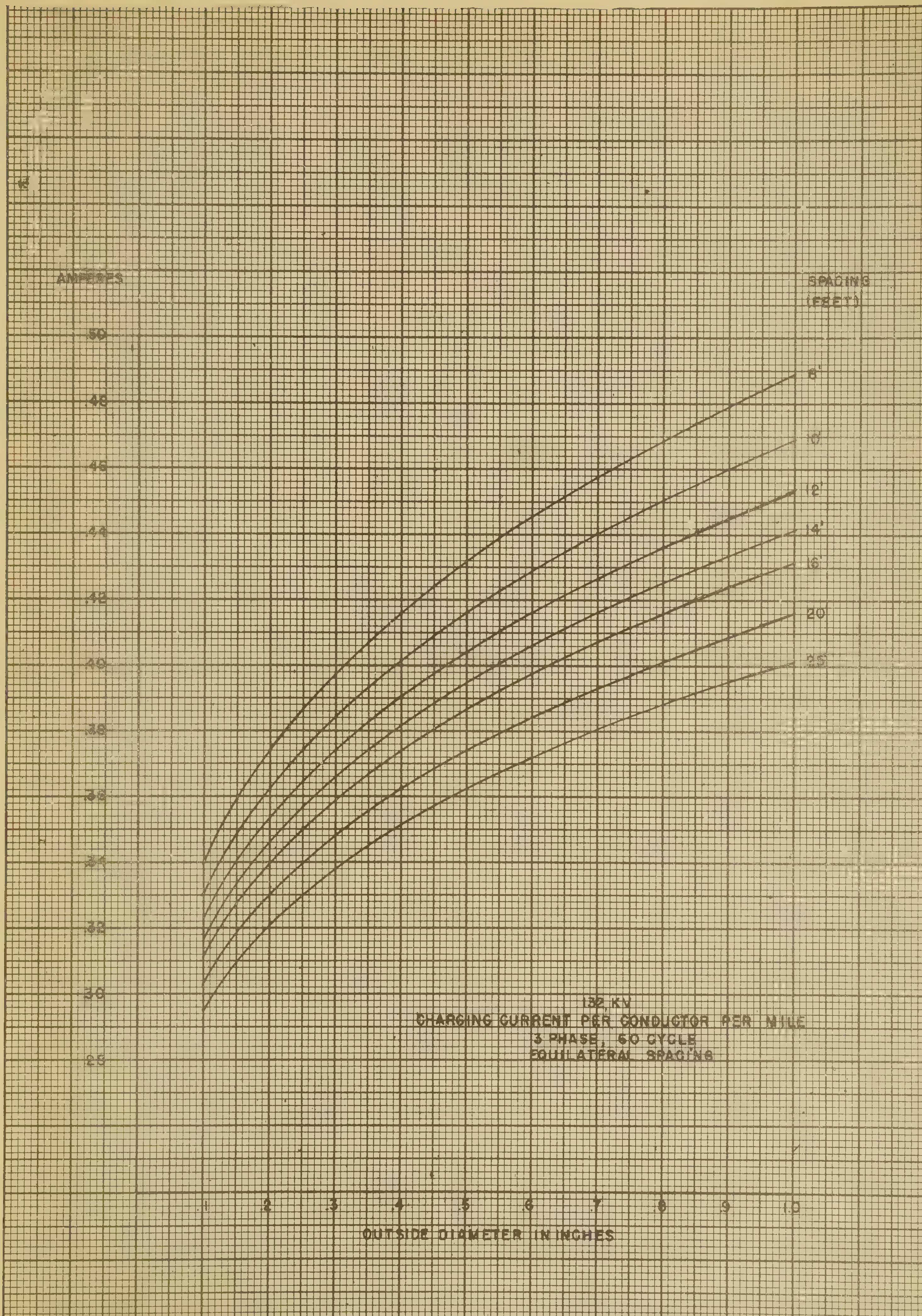


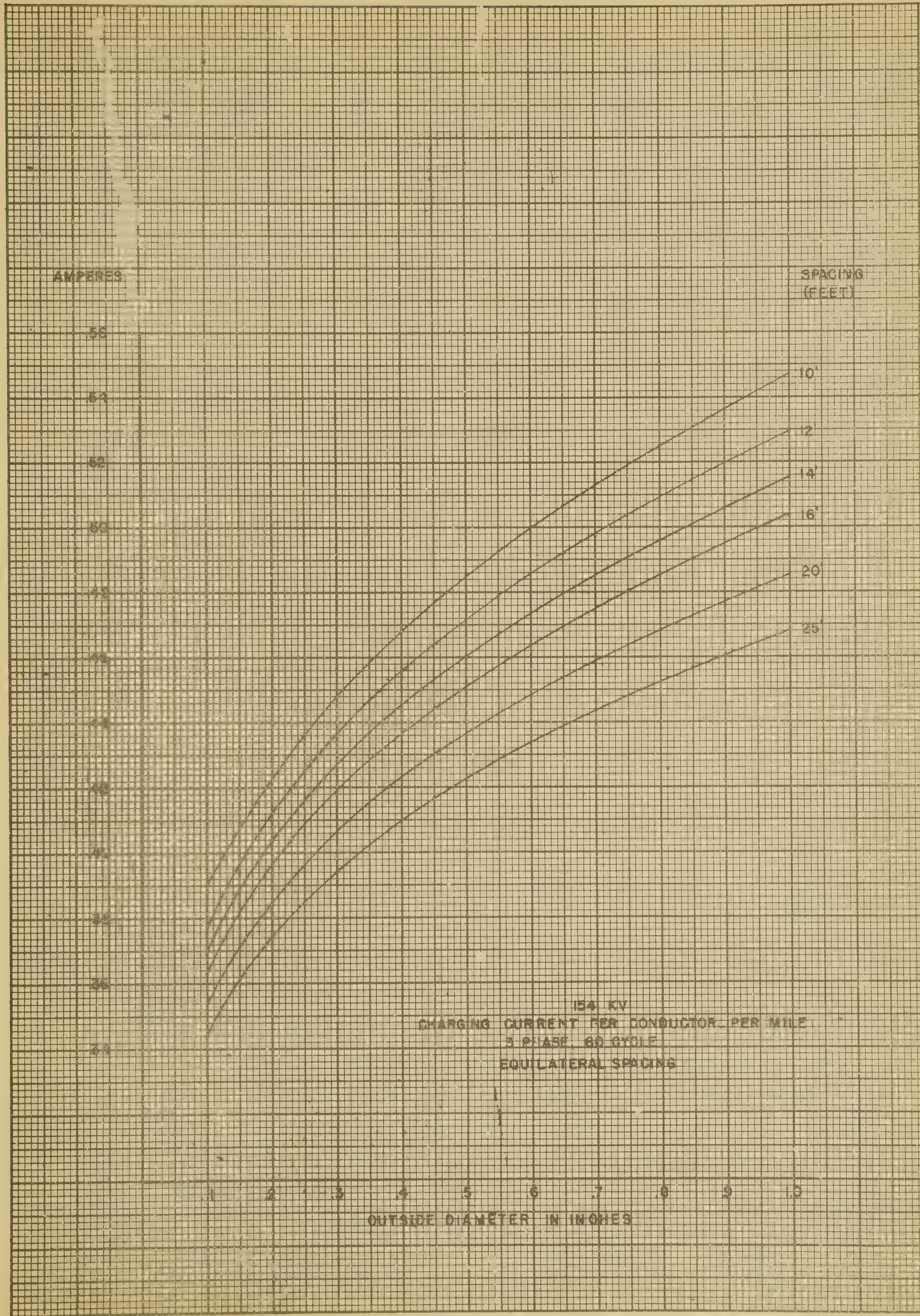
CURVE SHEET NO. 14

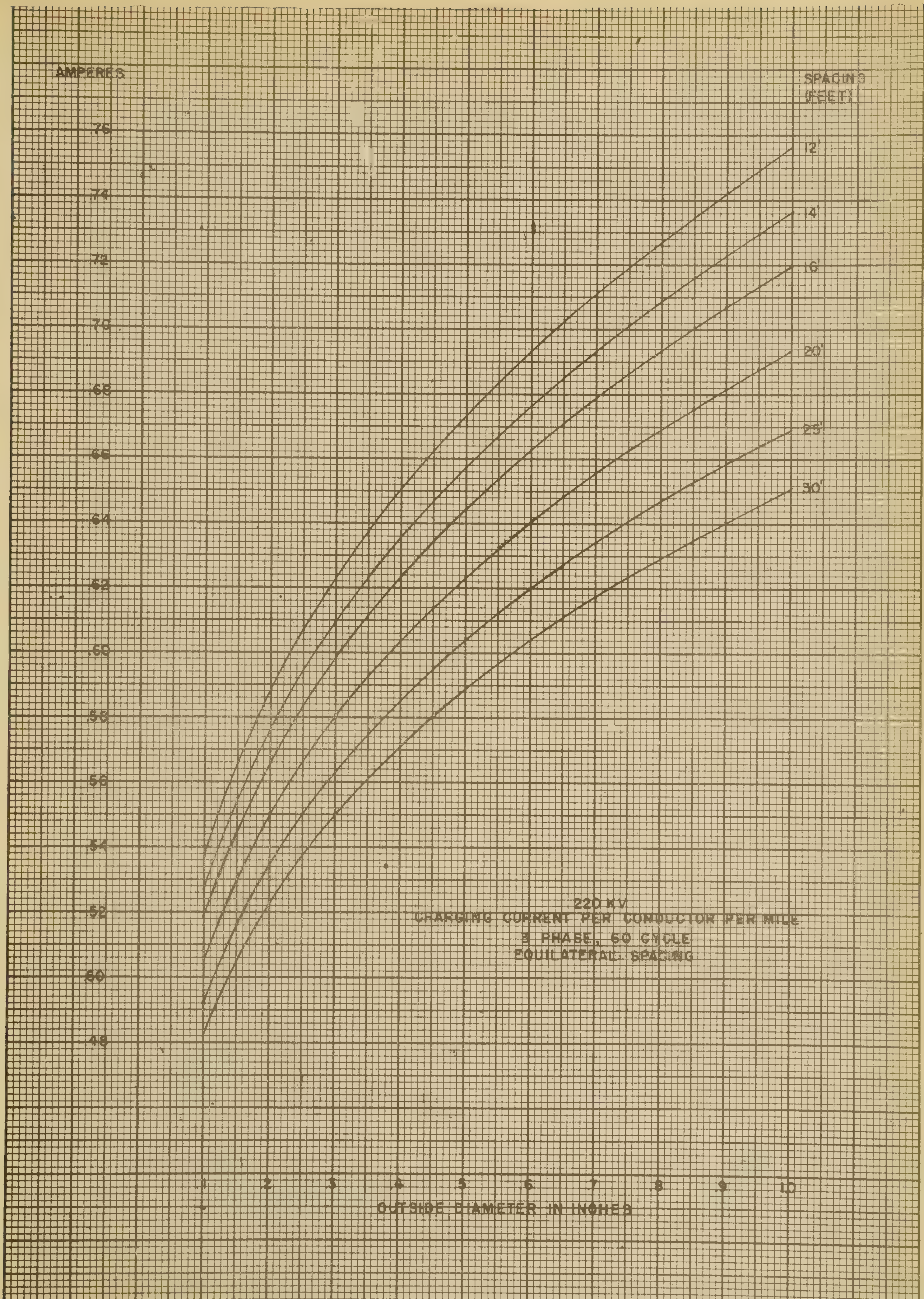


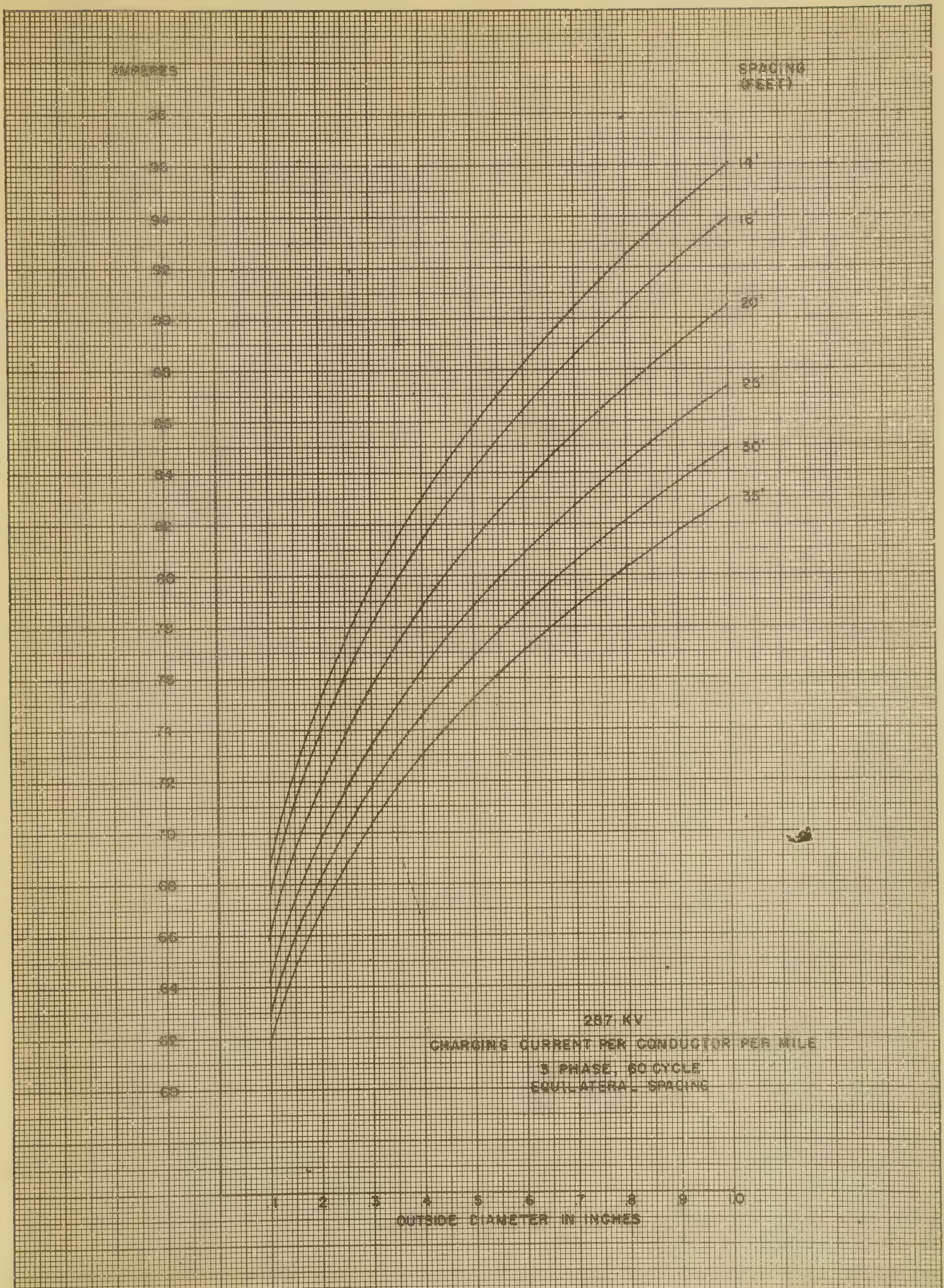
110 KV
3 PHASE, 60 CYCLE
OUTSIDE DIAMETER IN INCHES

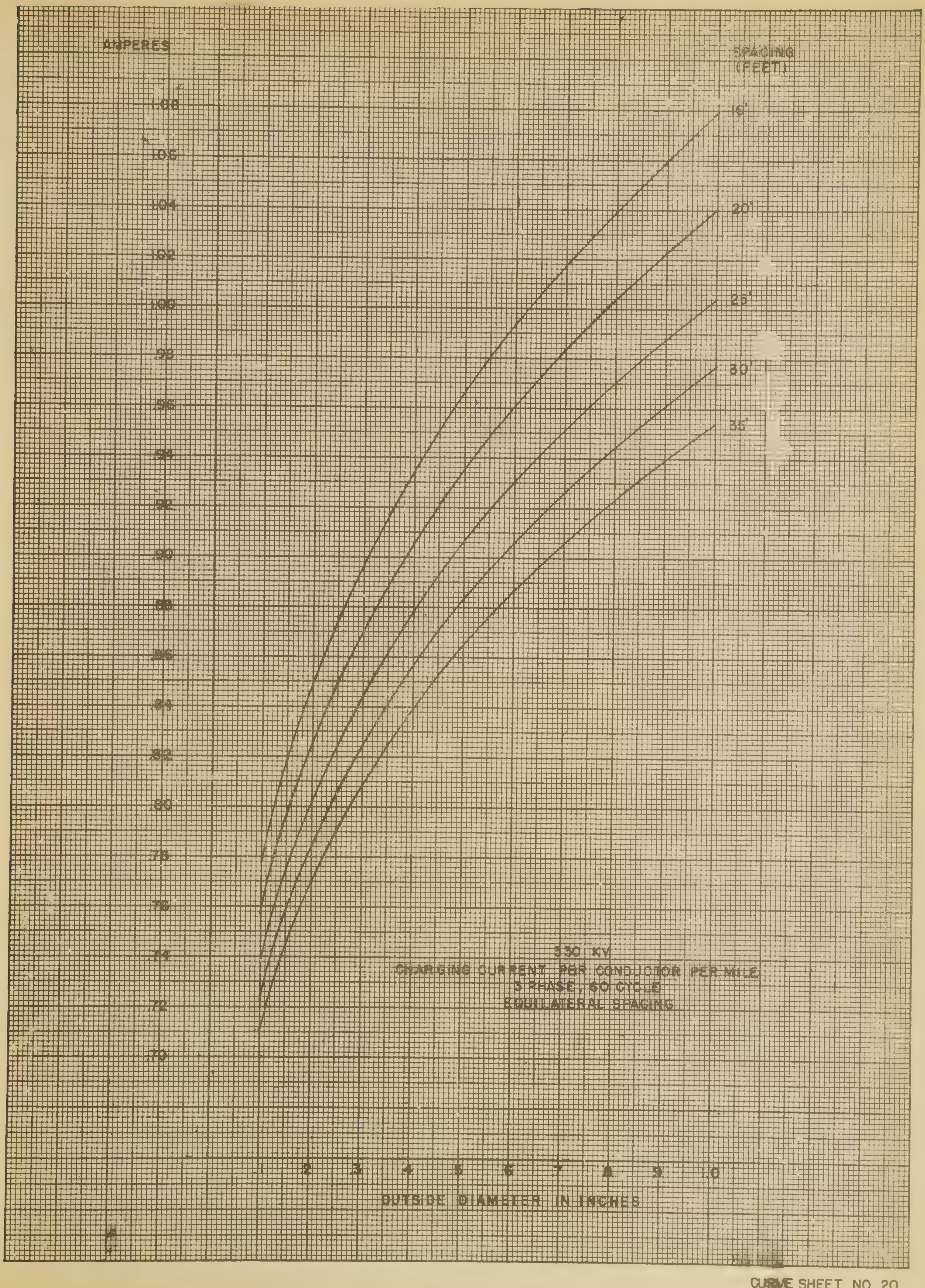


CURVE SHEET NO. 16

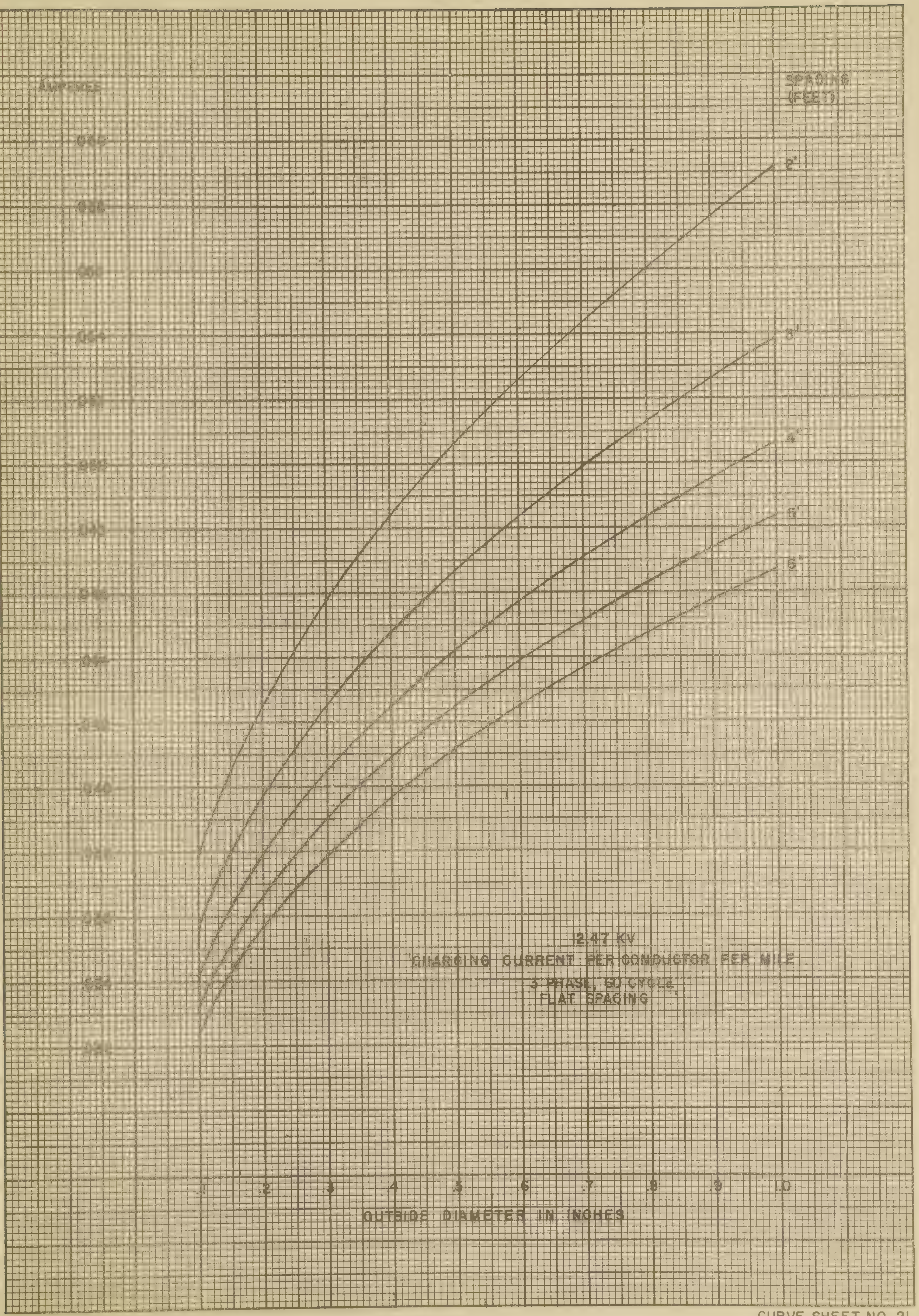

AMPERES
SPACING (FEET)
10'
12'
14'
16'
20'
25'
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
OUTSIDE DIAMETER IN INCHES
154 KV
CHARGING CURRENT PER CONDUCTOR PER MILE
3 PHASE, 60 CYCLE
EQUILATERAL SPACING


AMPERES
SPACING (FEET)
76
74
72
70
68
66
64
62
60
58
56
54
52
50
48
12'
14'
16'
20'
25'
30'
220 KV
CHARGING CURRENT PER CONDUCTOR PER MILE
3 PHASE, 60 CYCLE
EQUILATERAL SPACING
1
2
3
4
5
6
7
8
9
10
OUTSIDE DIAMETER IN INCHES


AMPERES
94
92
90
88
86
84
82
80
78
76
74
72
70
68
66
64
62
60
SPACING (FEET)
14'
16'
20'
25'
30'
35'
287 KV
CHARGING CURRENT PER CONDUCTOR PER MILE
3 PHASE, 60 CYCLE
EQUILATERAL SPACING
1
2
3
4
5
6
7
8
9
10
OUTSIDE DIAMETER IN INCHES



CURVE SHEET NO. 20



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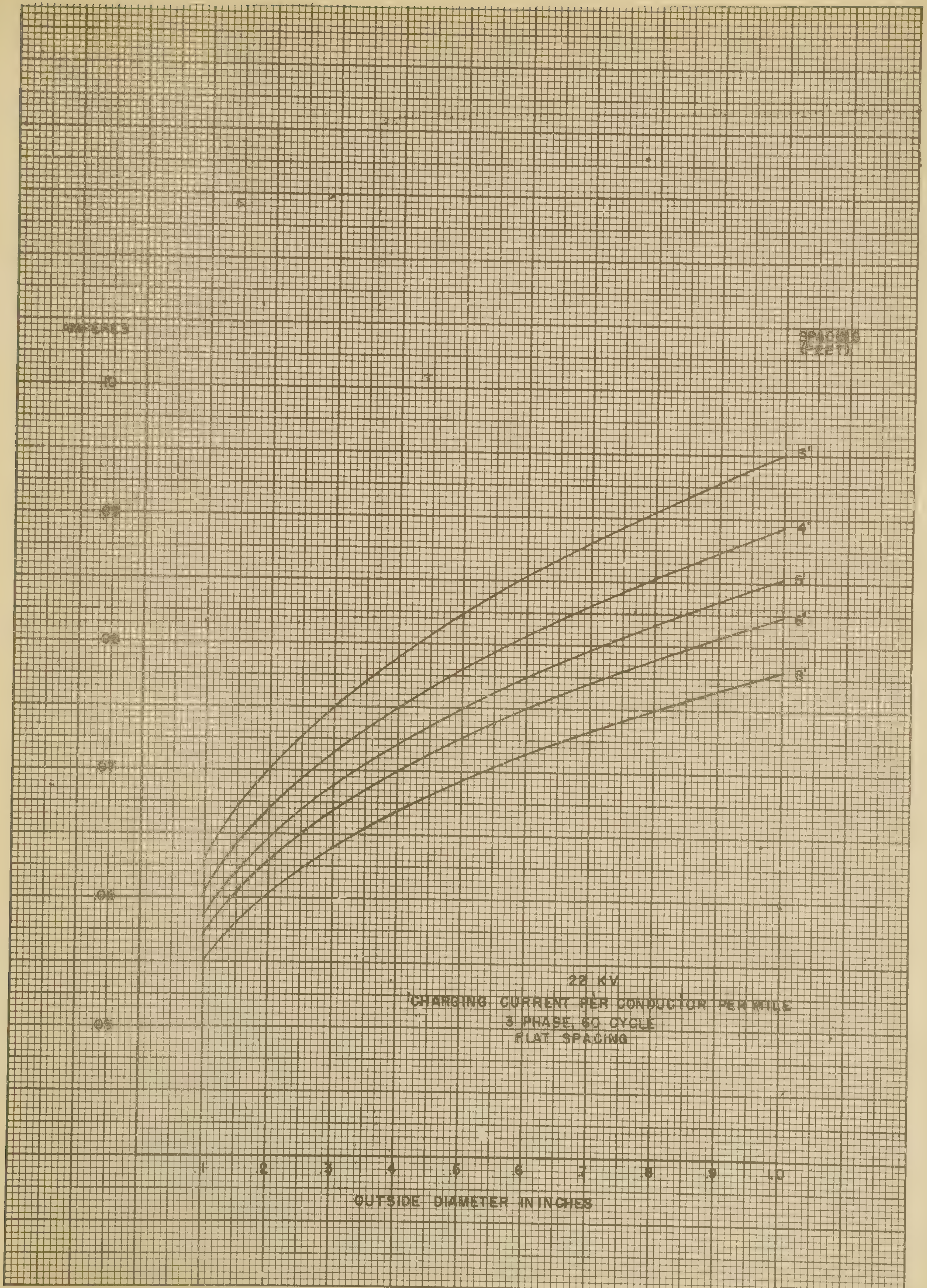
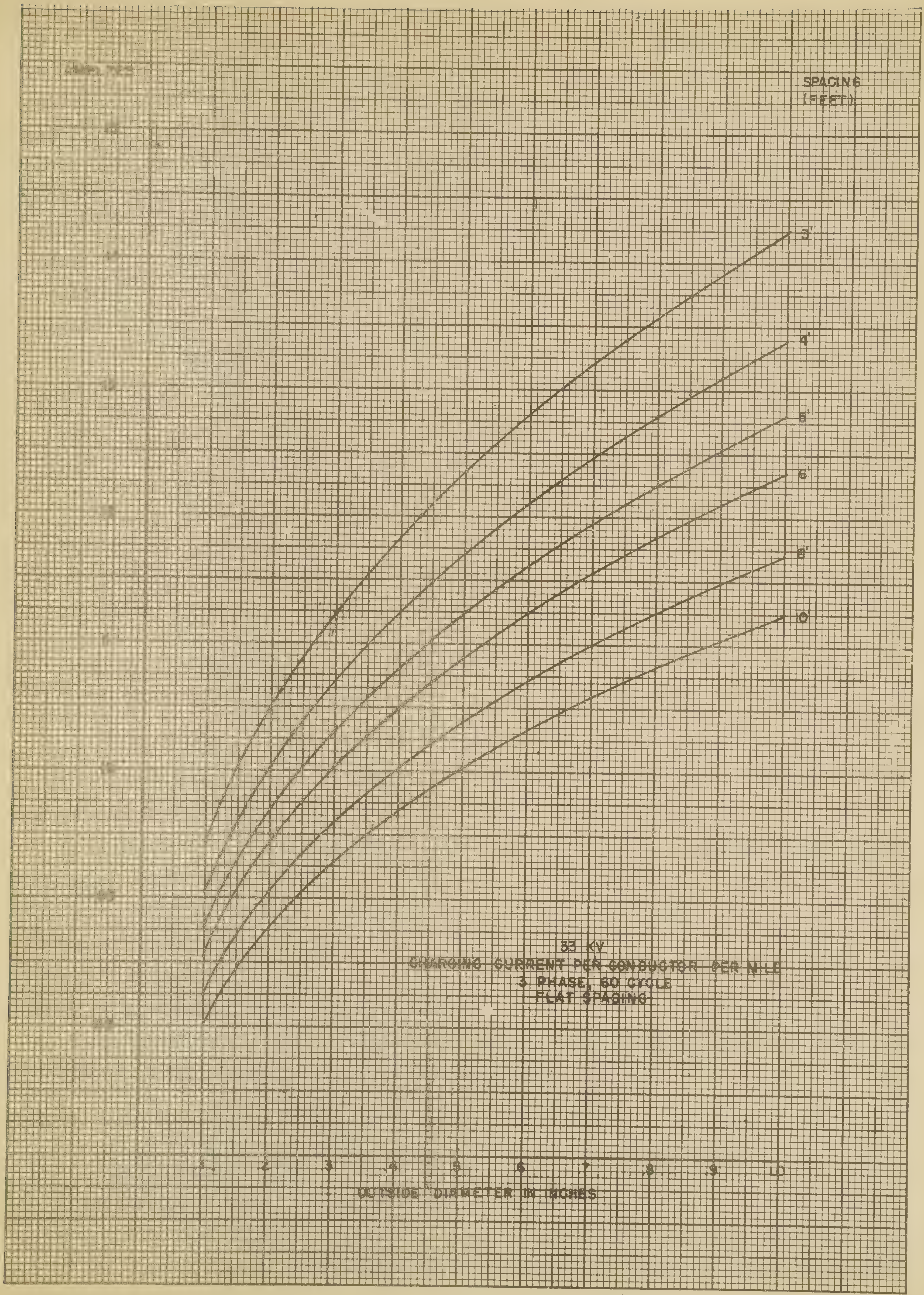
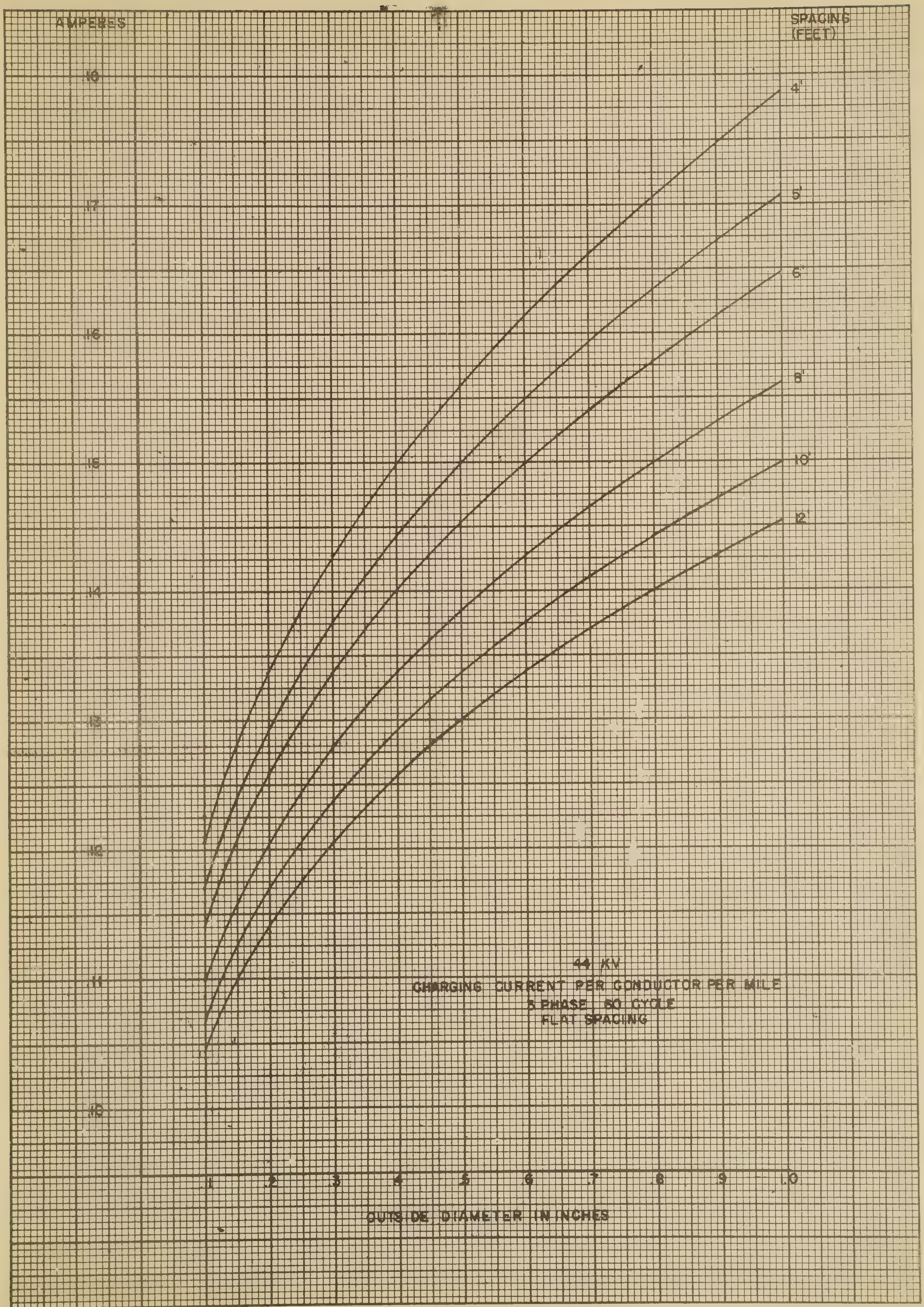

AMPERES
.10
.09
.08
.07
.06
.05
SPACING (FEET)
3'
4'
5'
6'
8'
22 KV
CHARGING CURRENT PER CONDUCTOR PER MILE
3 PHASE, 60 CYCLE
FLAT SPACING
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
OUTSIDE DIAMETER IN INCHES



CURVE SHEET NO. 23



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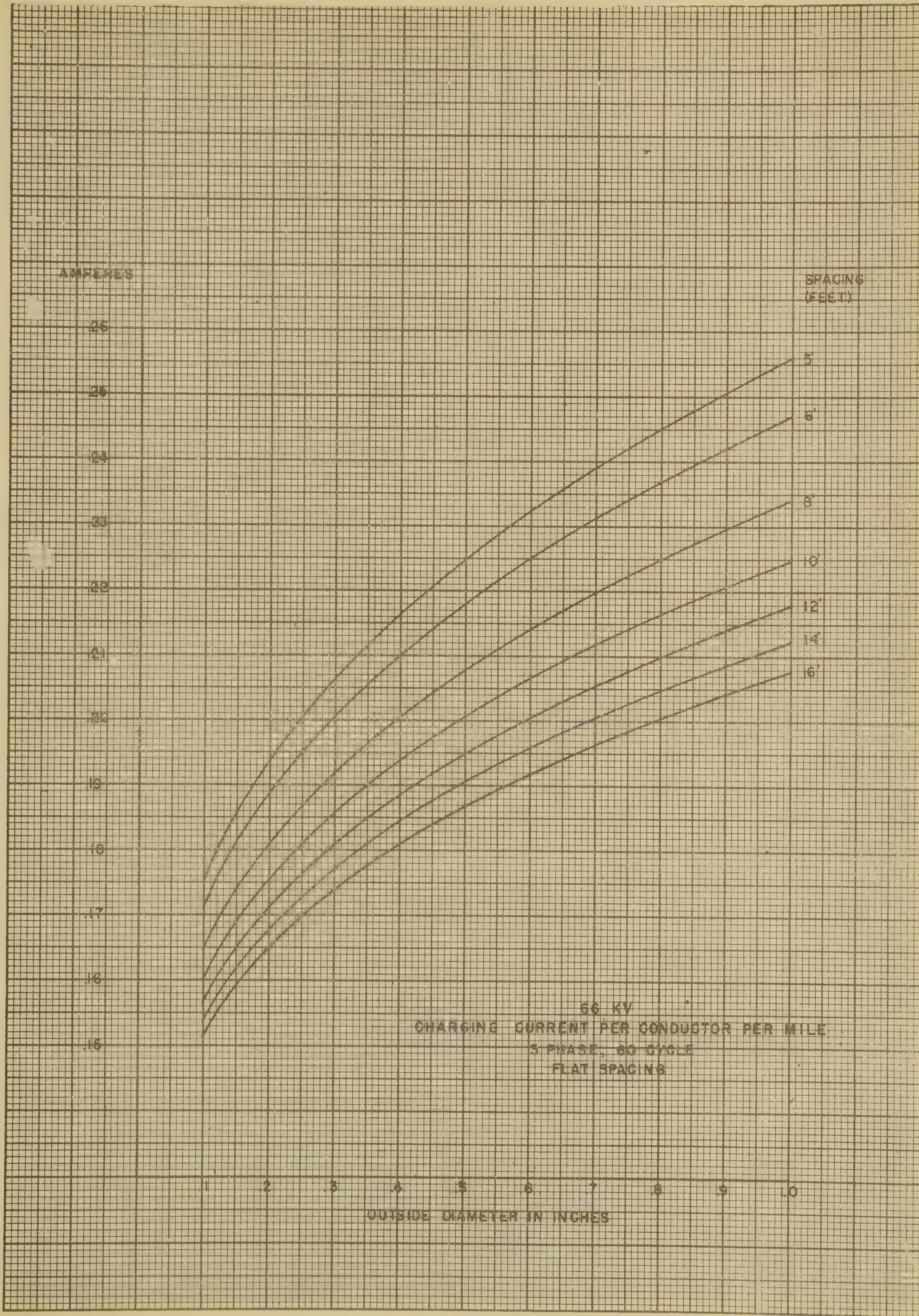

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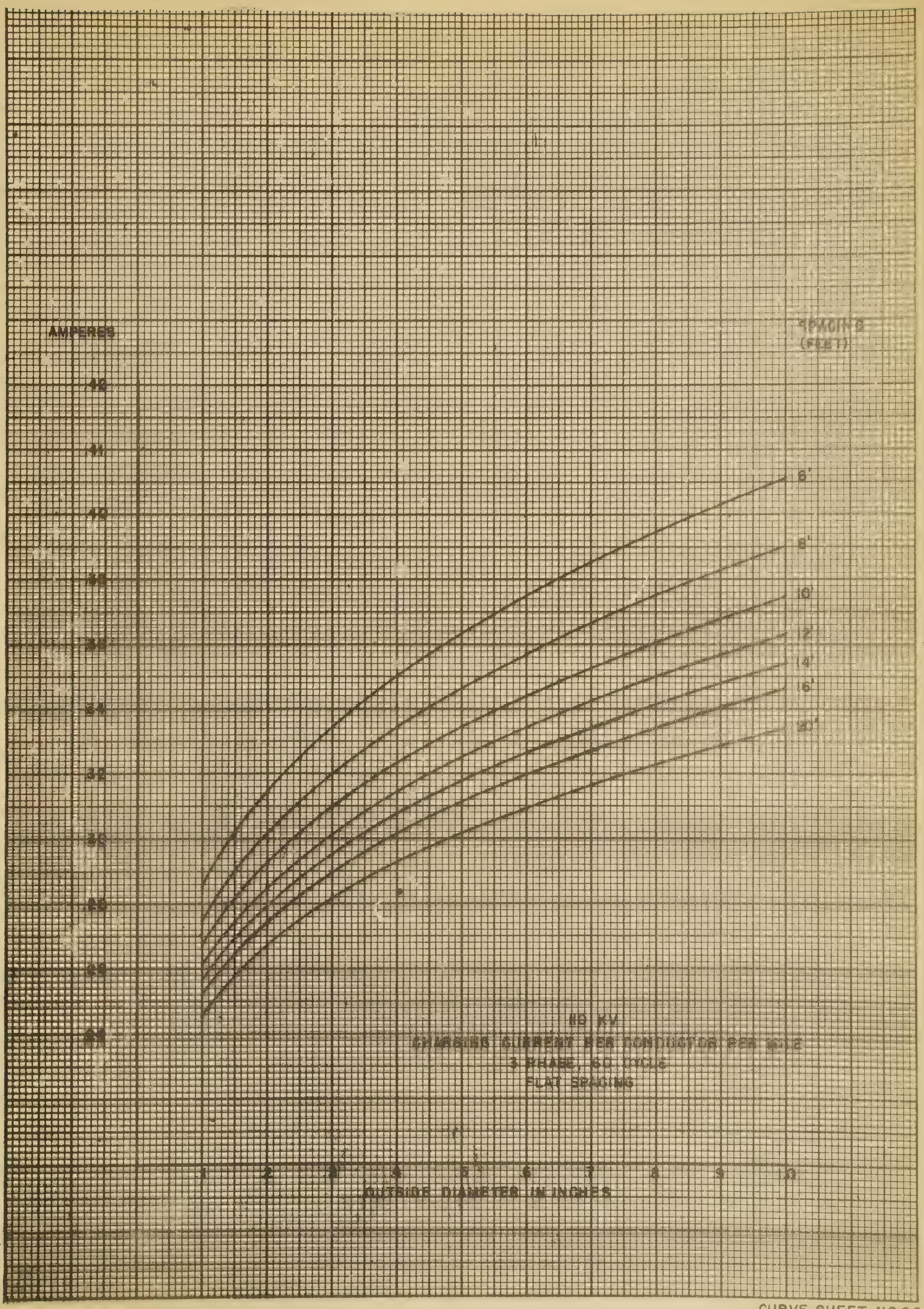

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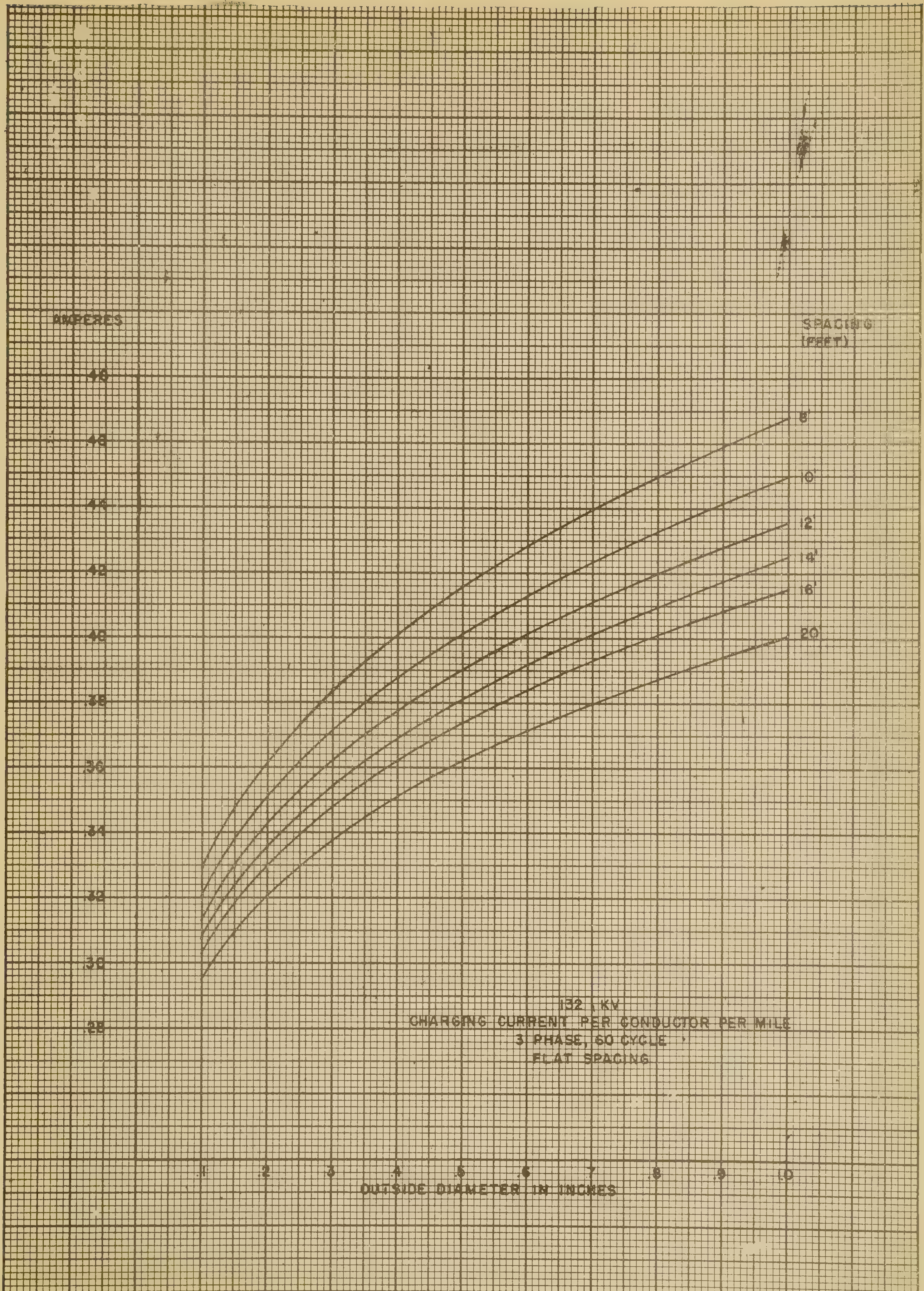

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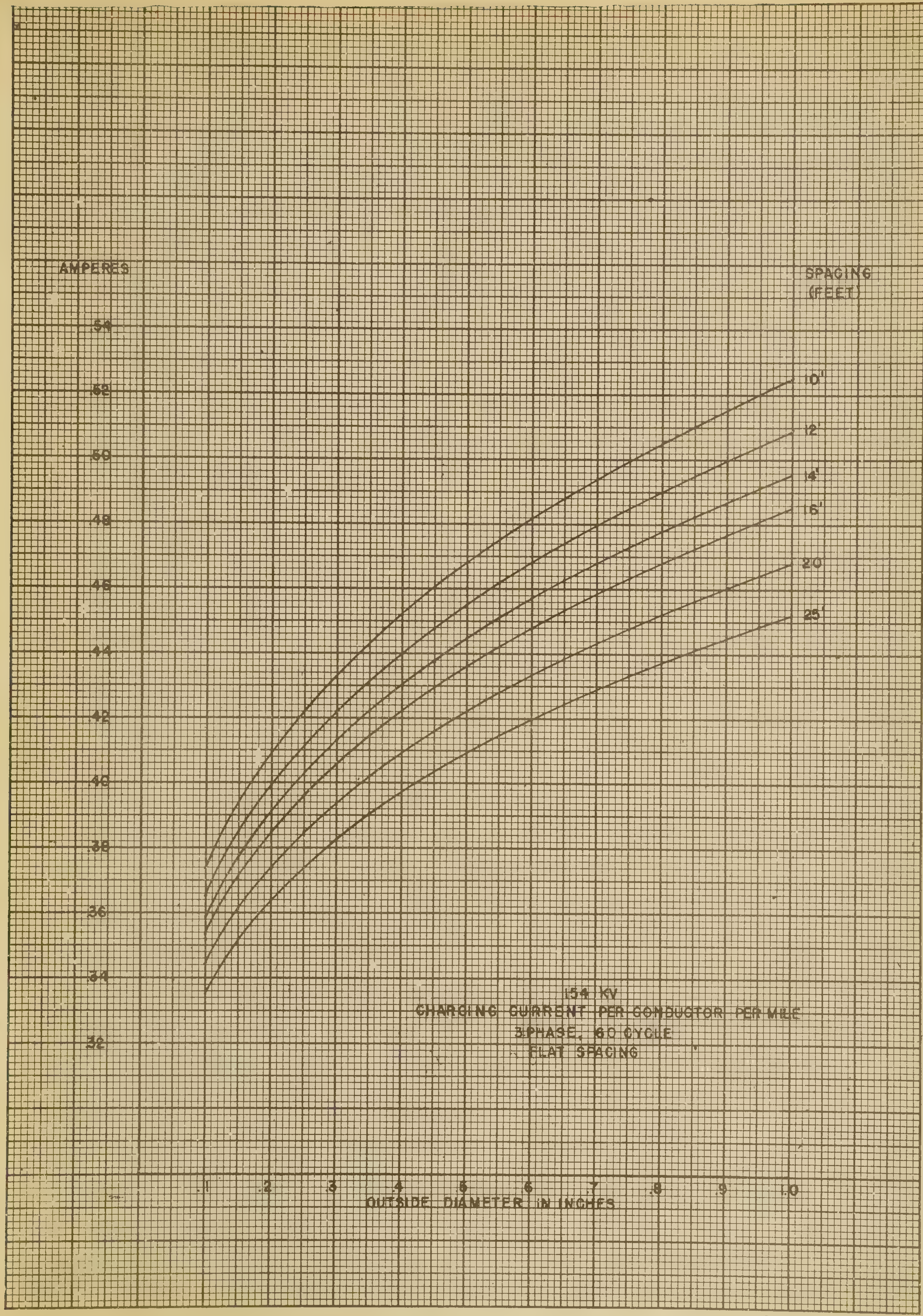

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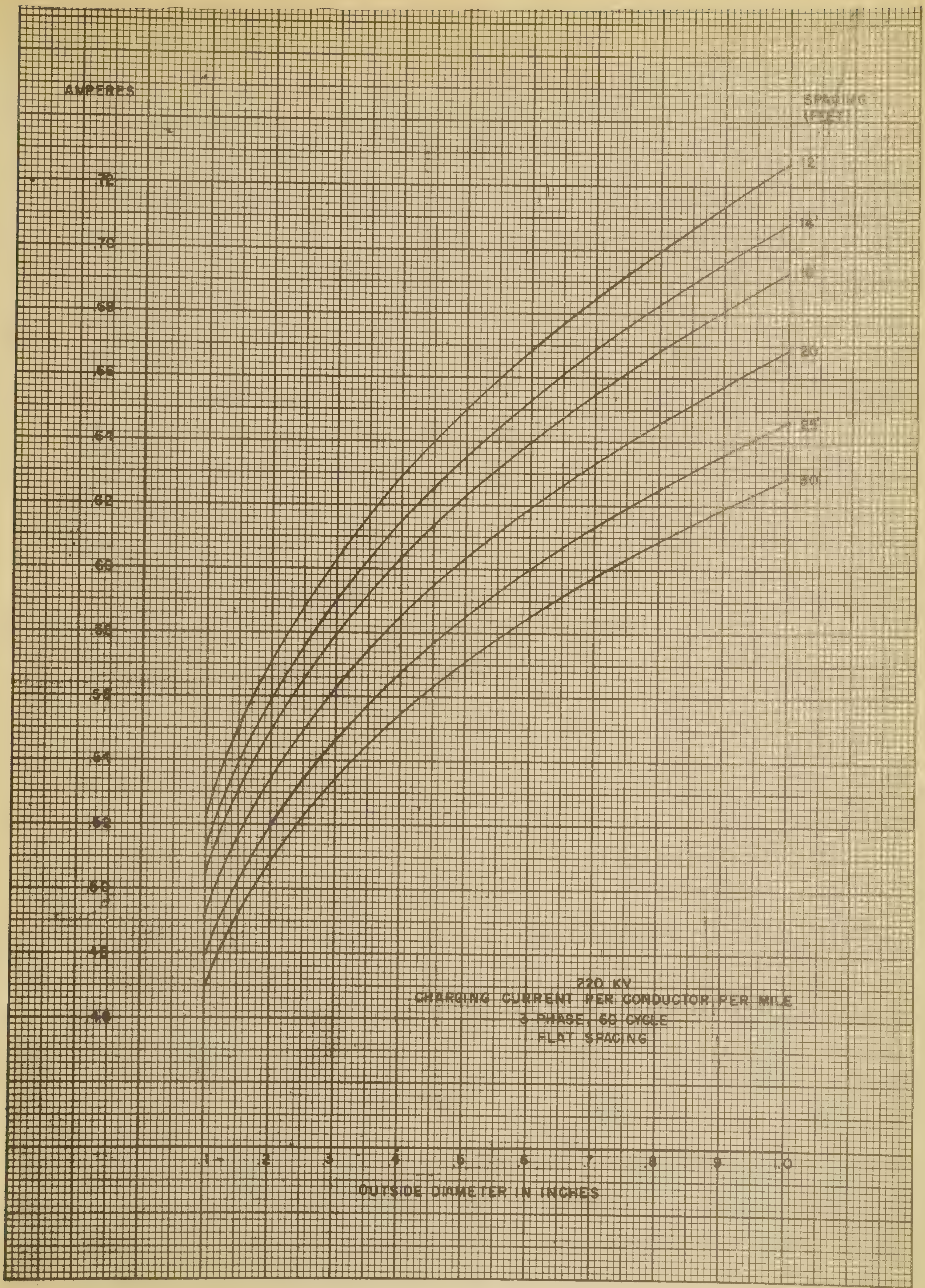
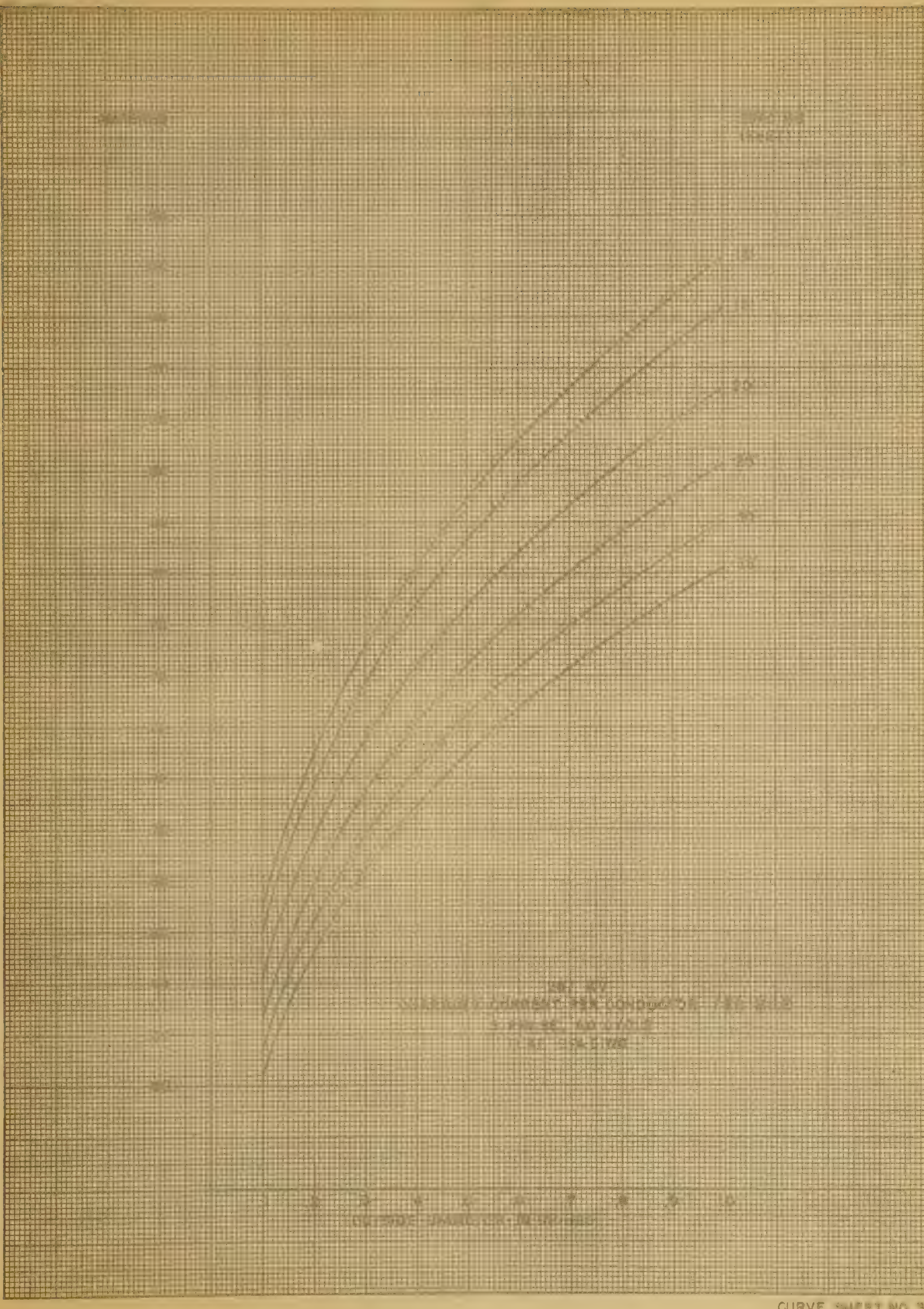
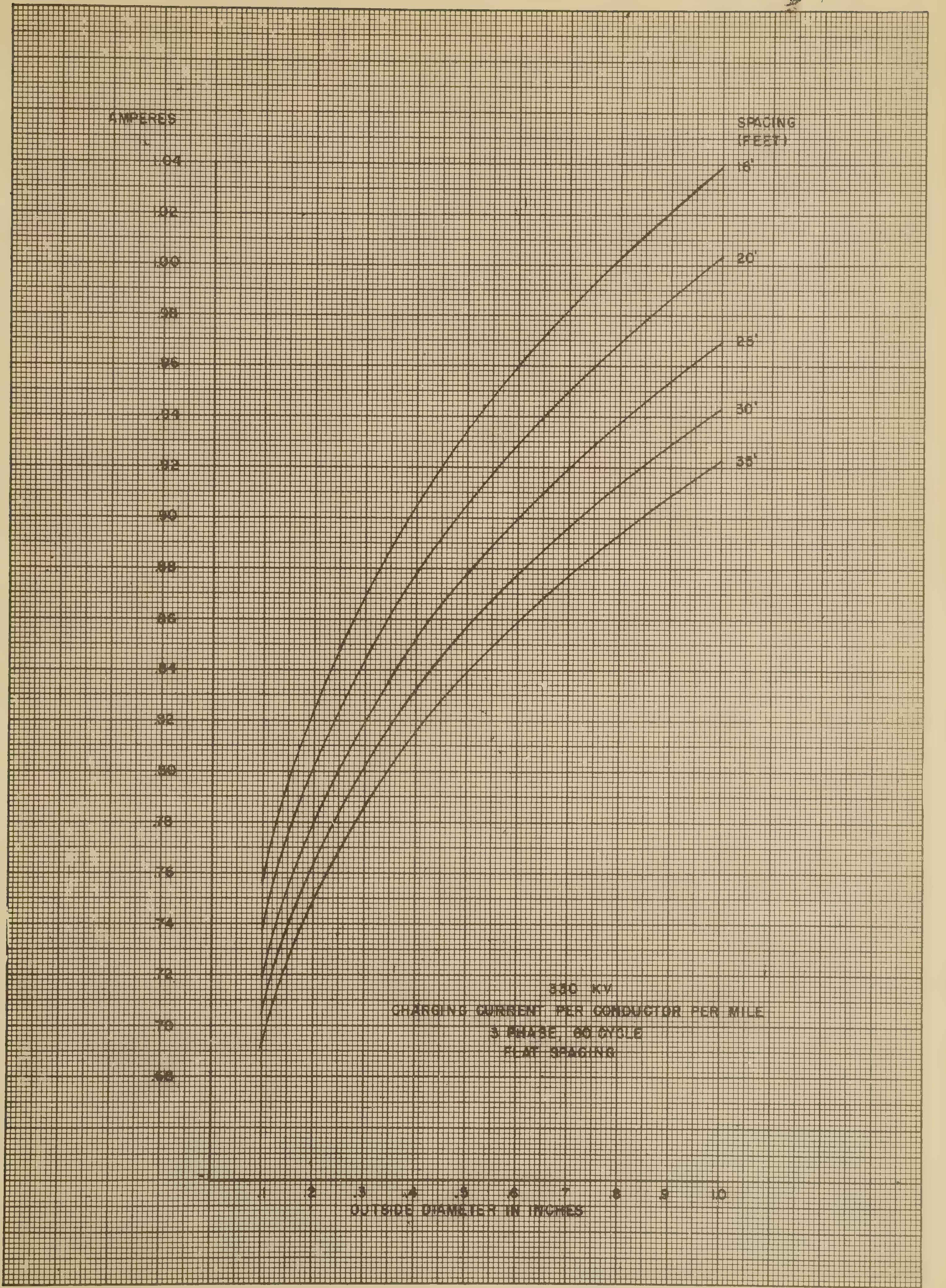
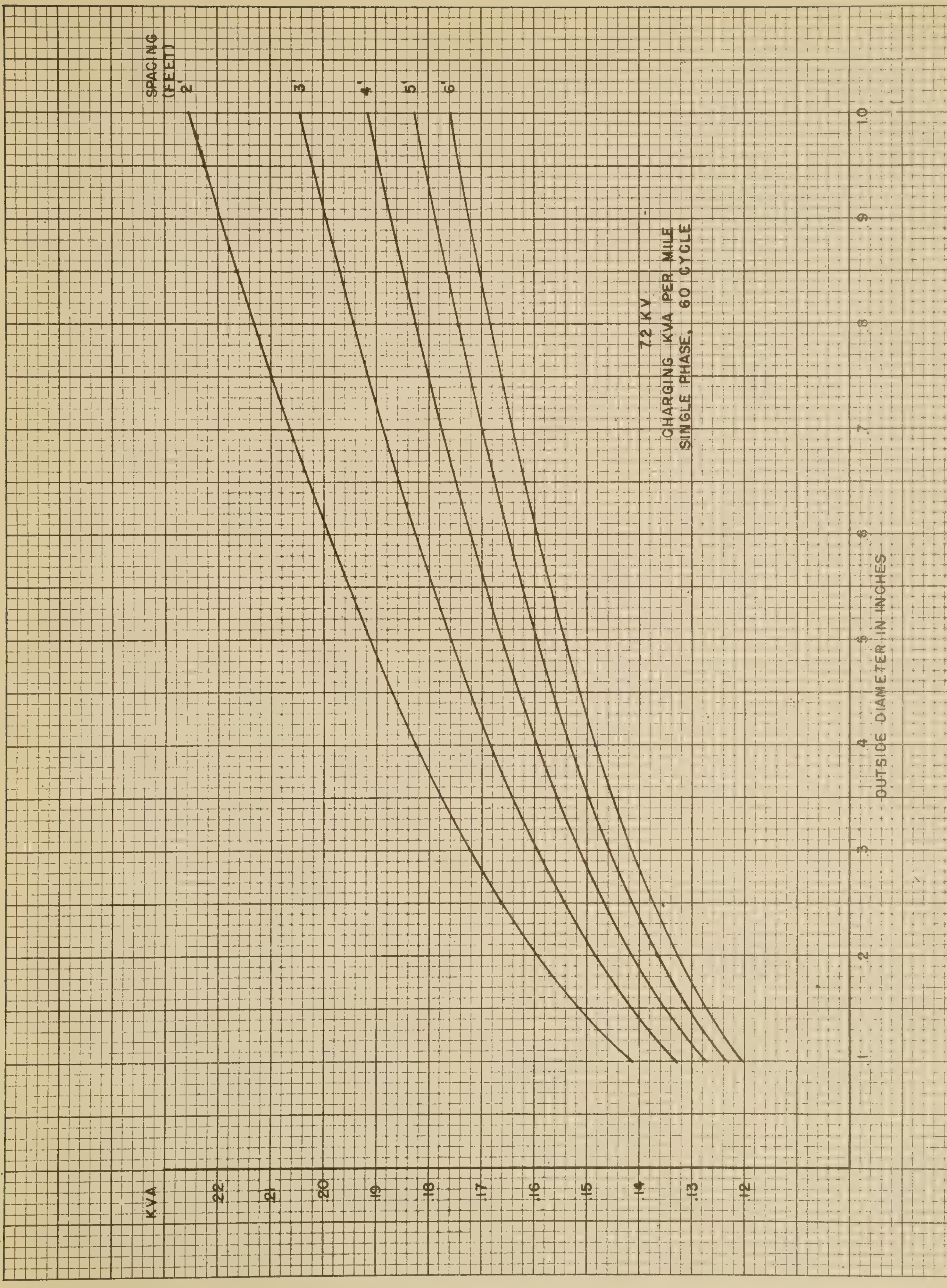


CURVE SHEET NO. 29

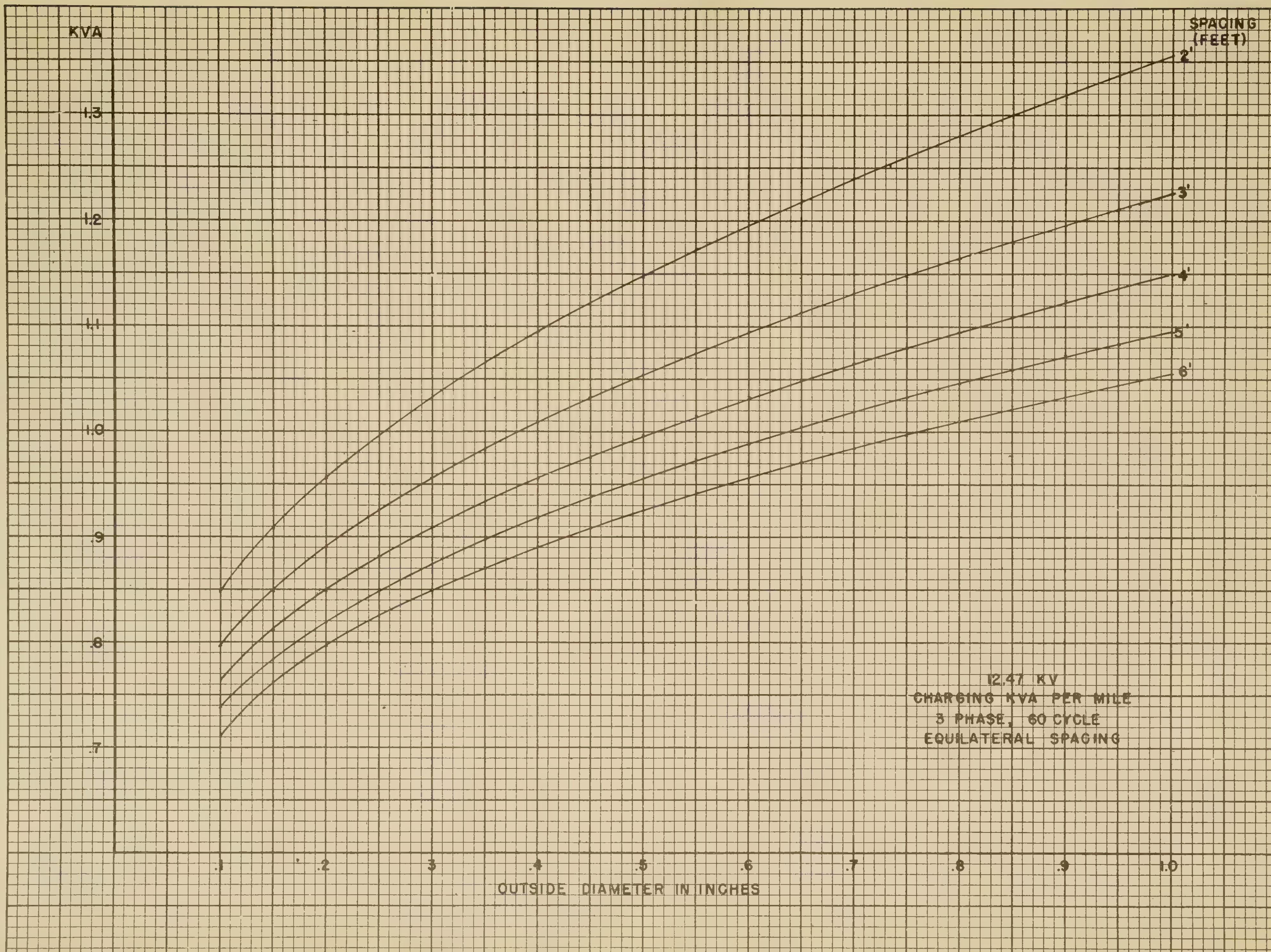


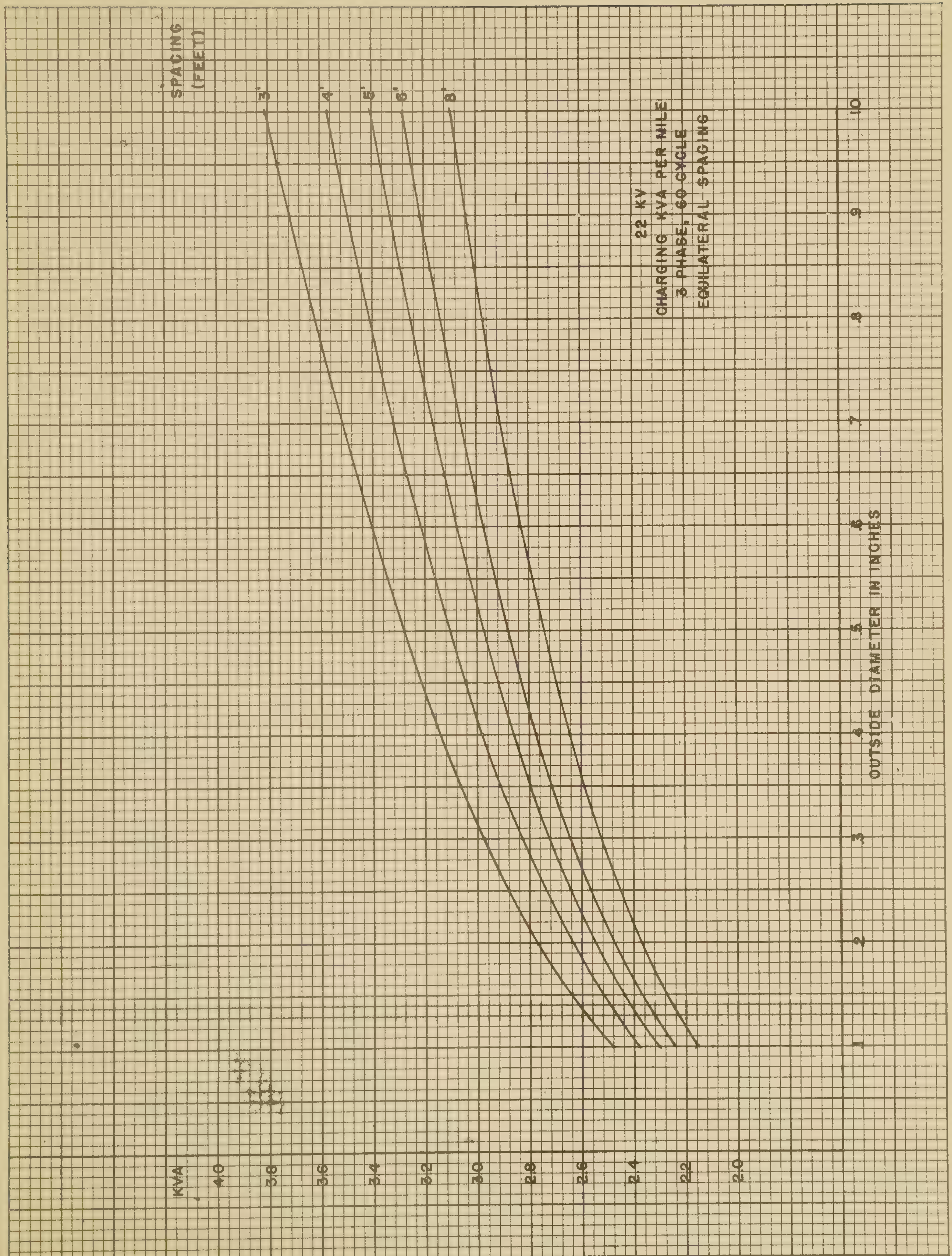
CURVE SHEET NO. 30


AMPERES
1.04
1.02
1.00
.98
.96
.94
.92
.90
.88
.86
.84
.82
.80
.78
.76
.74
.72
.70
.68
SPACING
(FEET)
15'
20'
25'
30'
35'
330 KV
CHARGING CURRENT PER CONDUCTOR PER MILE
3 PHASE, 60 CYCLE
FLAT SPACING
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
OUTSIDE DIAMETER IN INCHES

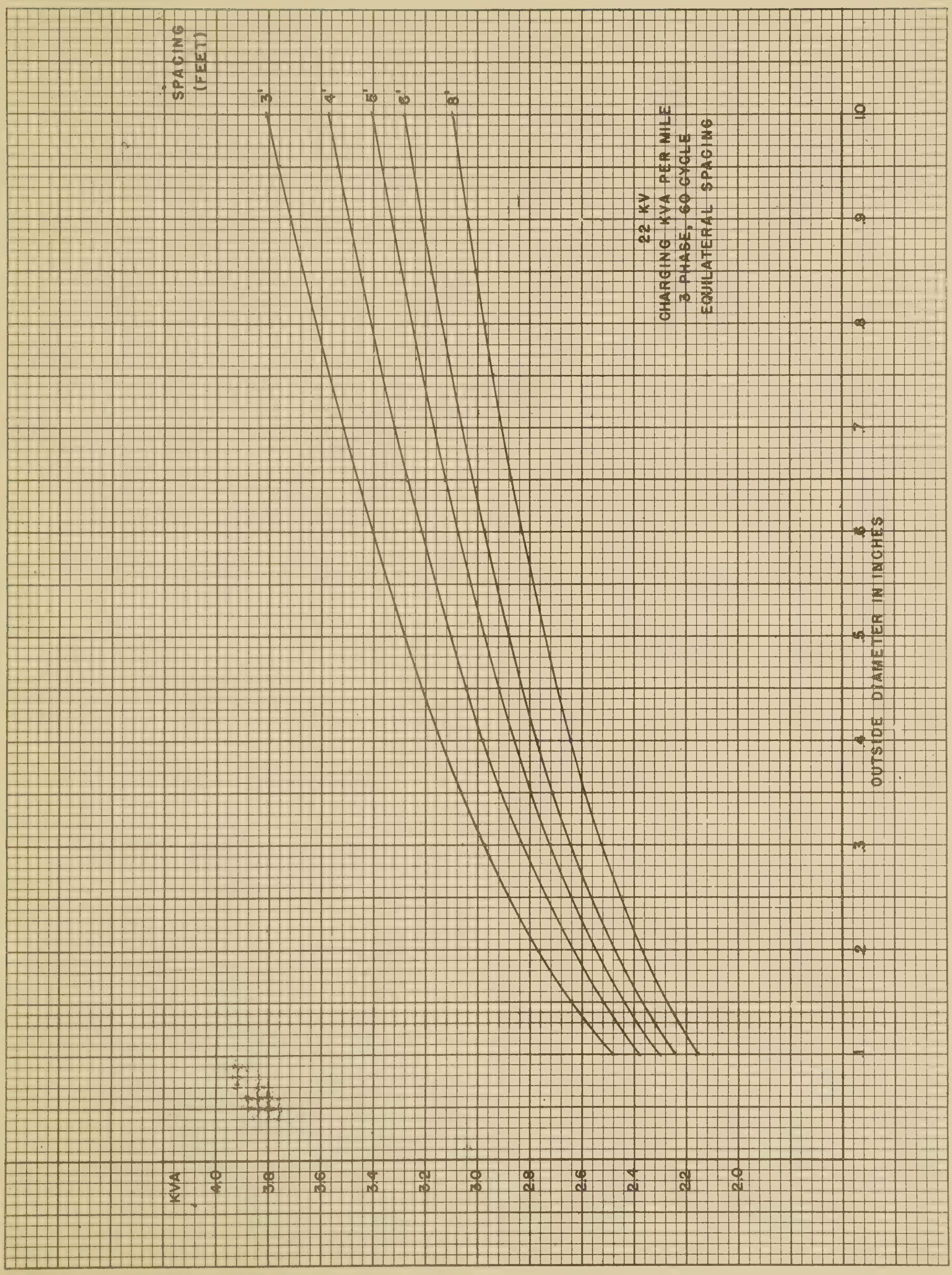


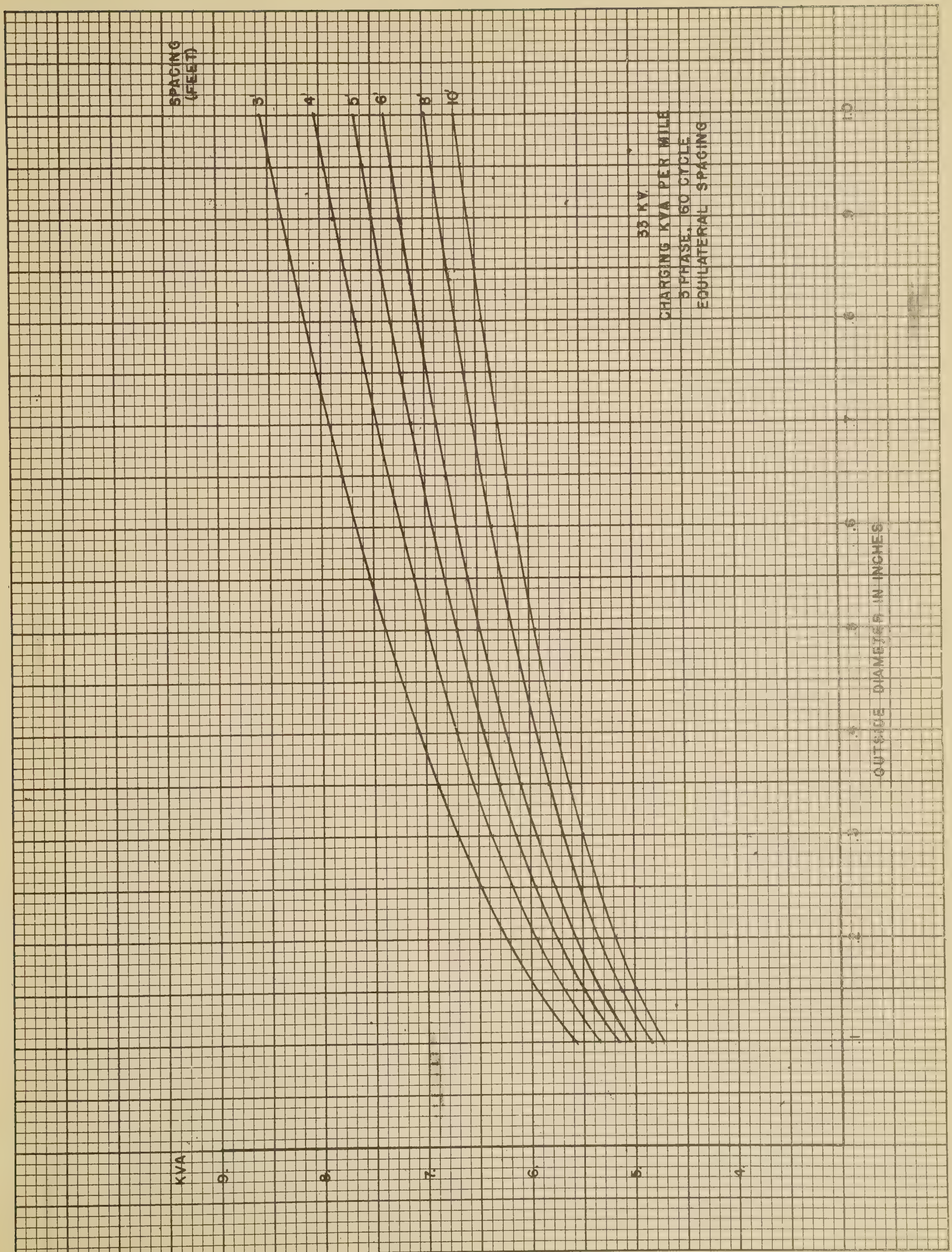
CURVE SHEET NO.32

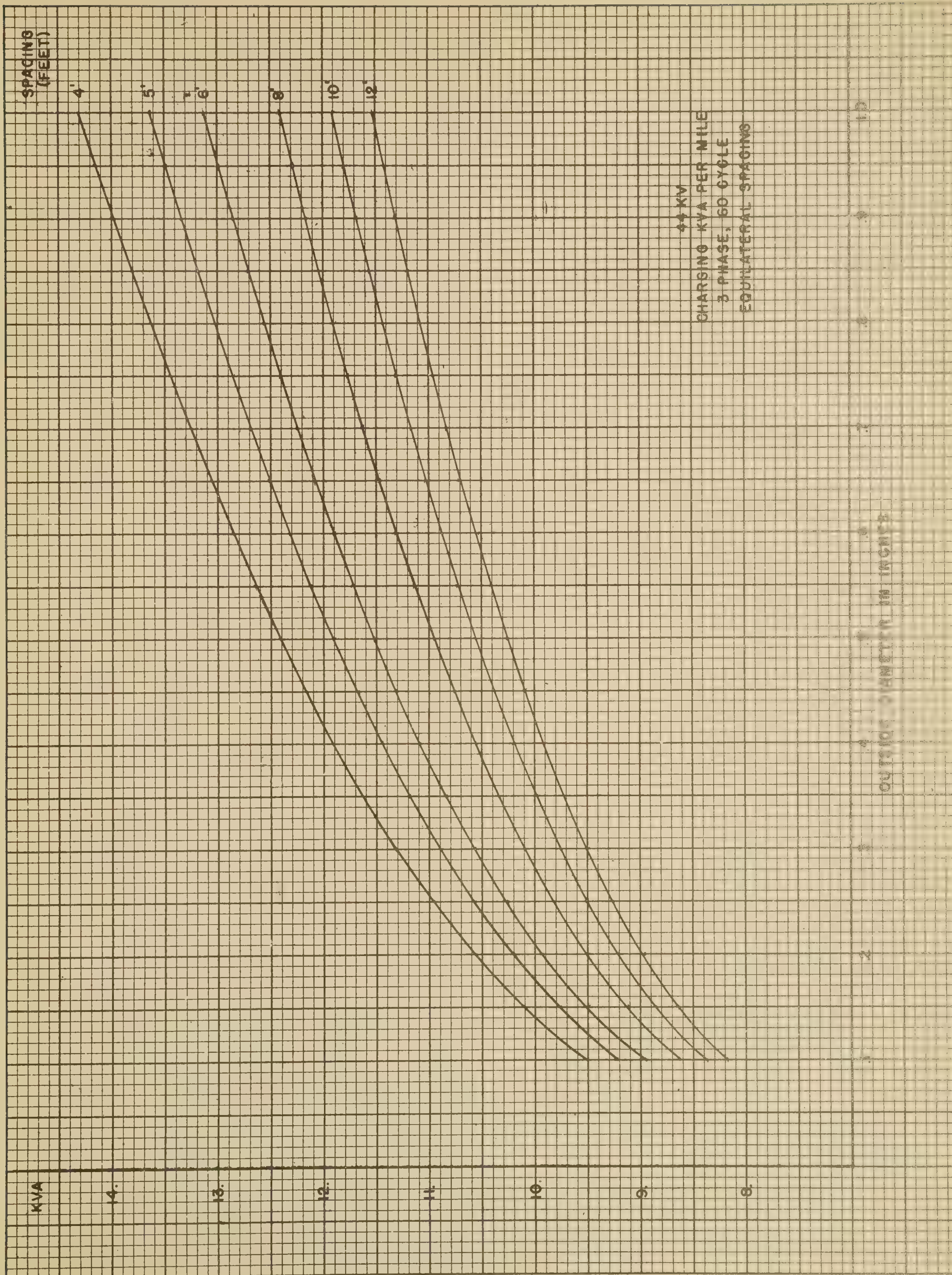

KVA
SPACING (FEET)
2'
3'
4'
5'
6'
1.3
1.2
1.1
1.0
.9
.8
.7
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
OUTSIDE DIAMETER IN INCHES
12.47 KV
CHARGING KVA PER MILE
3 PHASE, 60 CYCLE
EQUILATERAL SPACING

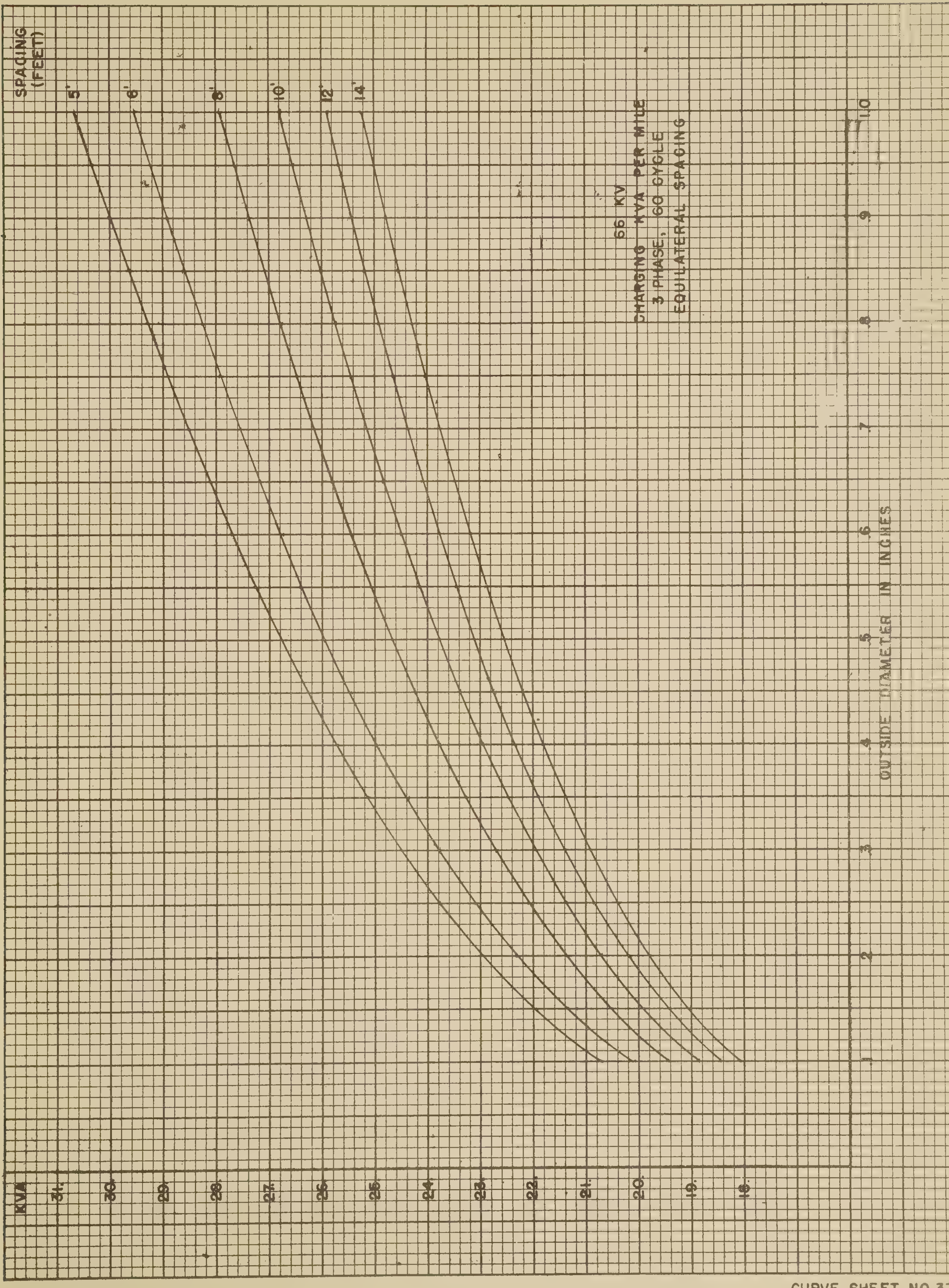


CURVE SHEET NO. 34

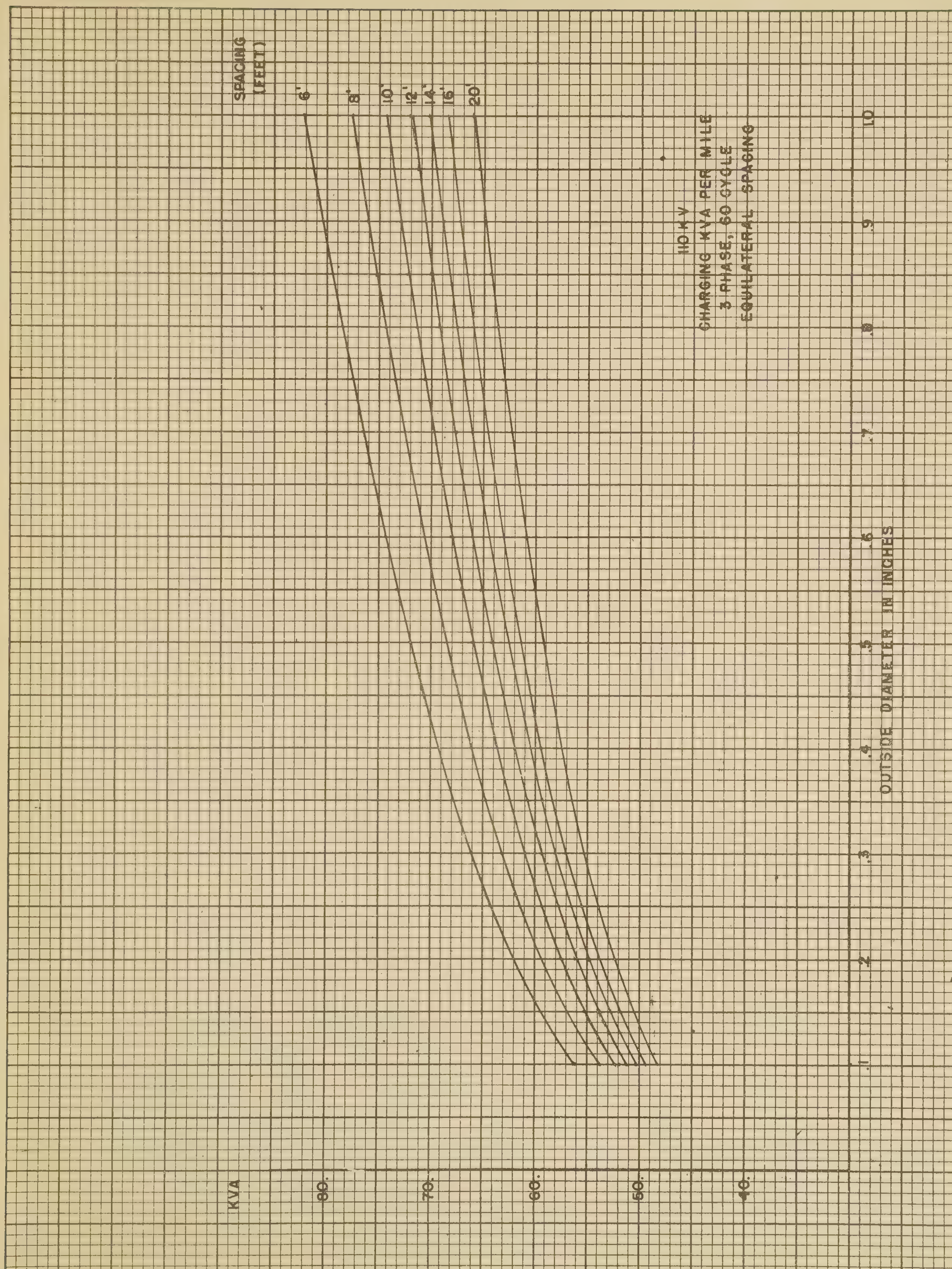

22 KV
CHARGING KVA PER MILE
3 PHASE, 60 CYCLE
EQUILATERAL SPACING
SPACING (FEET)
3'
4'
5'
6'
8'
KVA
4.0
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1
2
3
4
5
6
7
8
9
10
OUTSIDE DIAMETER IN INCHES

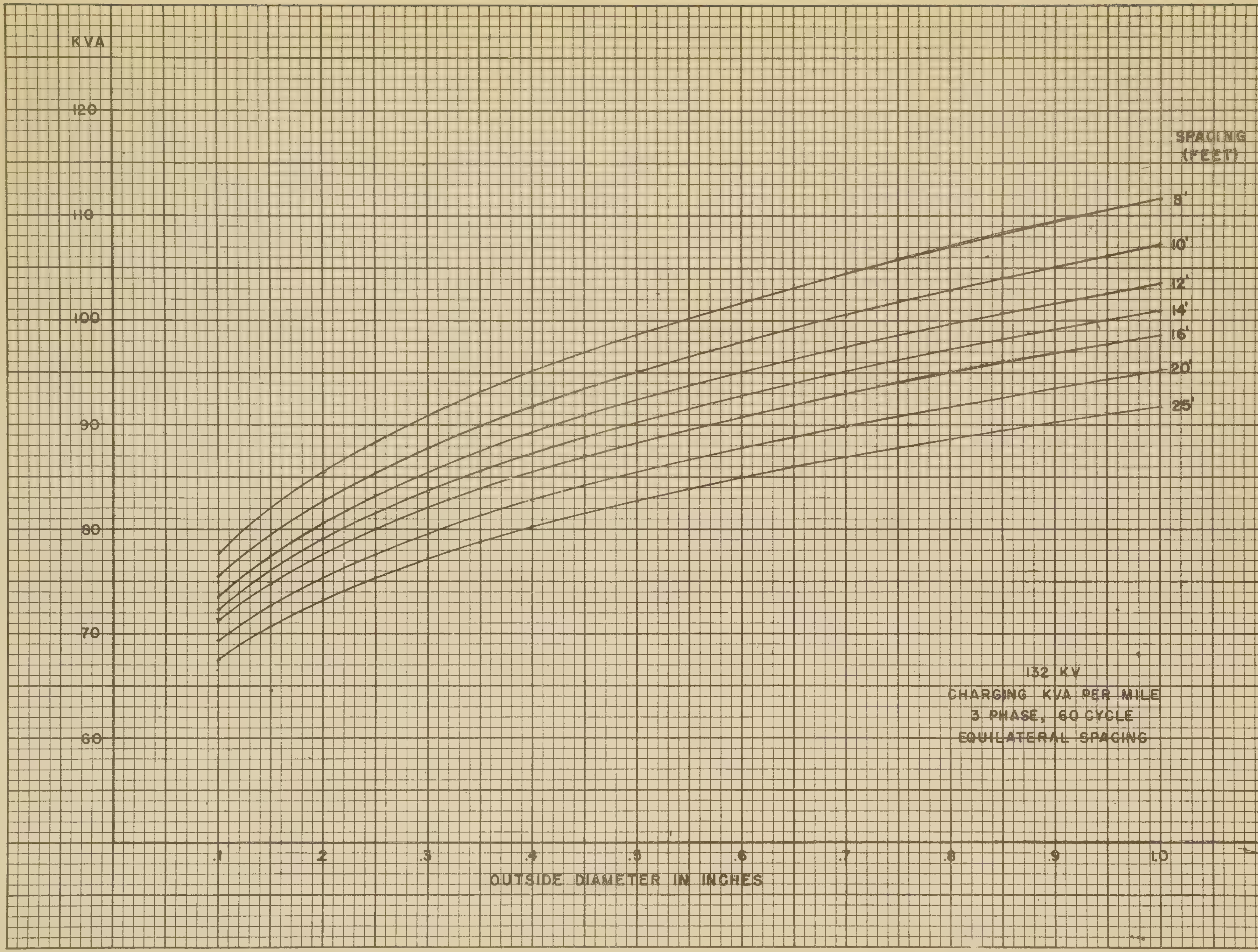

SPACING (FEET)
3'
4'
5'
6'
8'
10'
33 KV.
CHARGING KVA PER MILE
3 PHASE, 60 CYCLE
EQUILATERAL SPACING
KVA
9.
8.
7.
6.
5.
4.
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
OUTSIDE DIAMETER IN INCHES

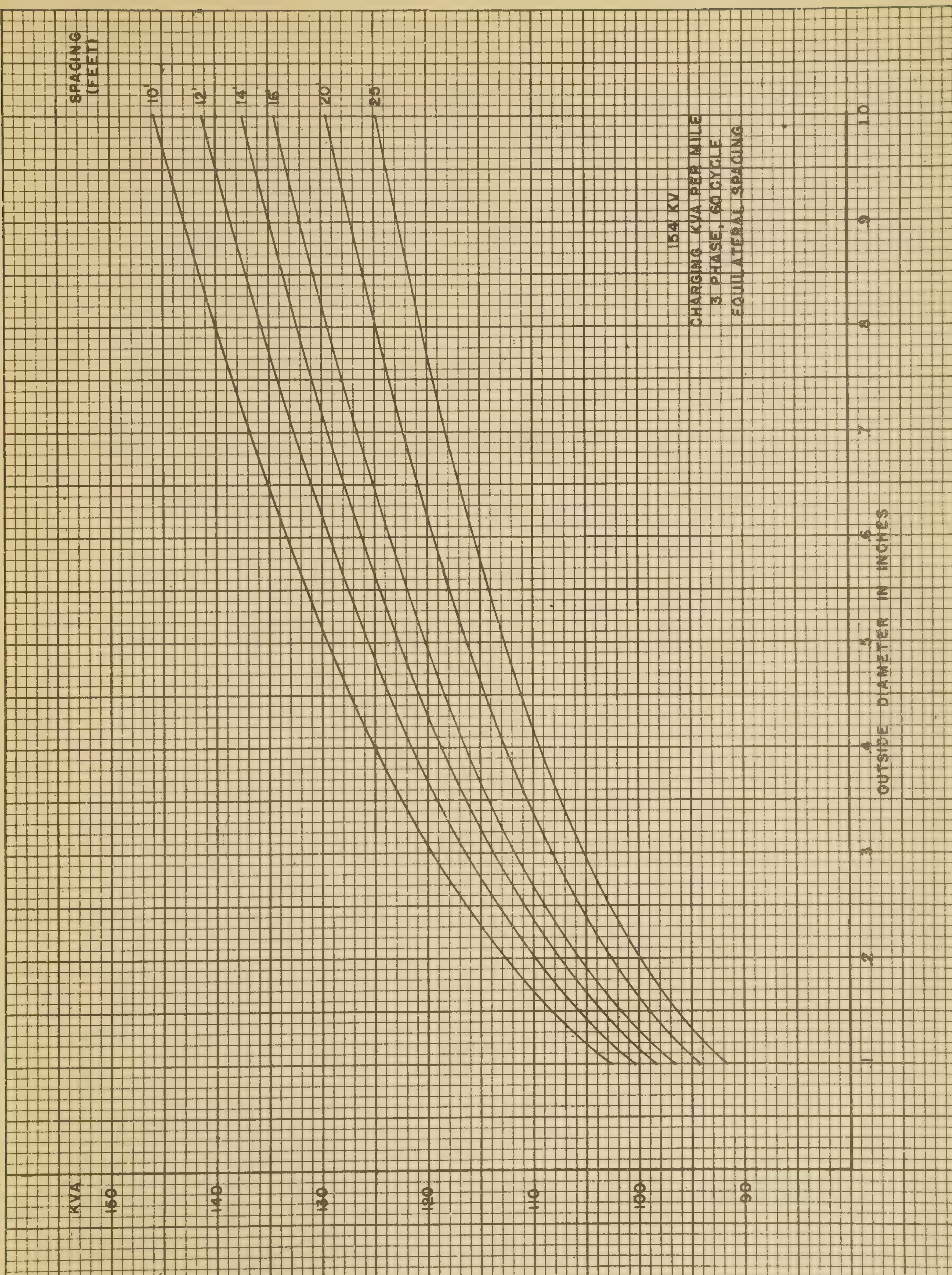

SPACING (FEET)
4'
5'
6'
8'
10'
12'
44 KV
CHARGING KVA PER MILE
3 PHASE, 60 CYCLE
EQUILATERAL SPACING
KVA
14.
13.
12.
11.
10.
9.
8.
OUTSIDE DIAMETER IN INCHES

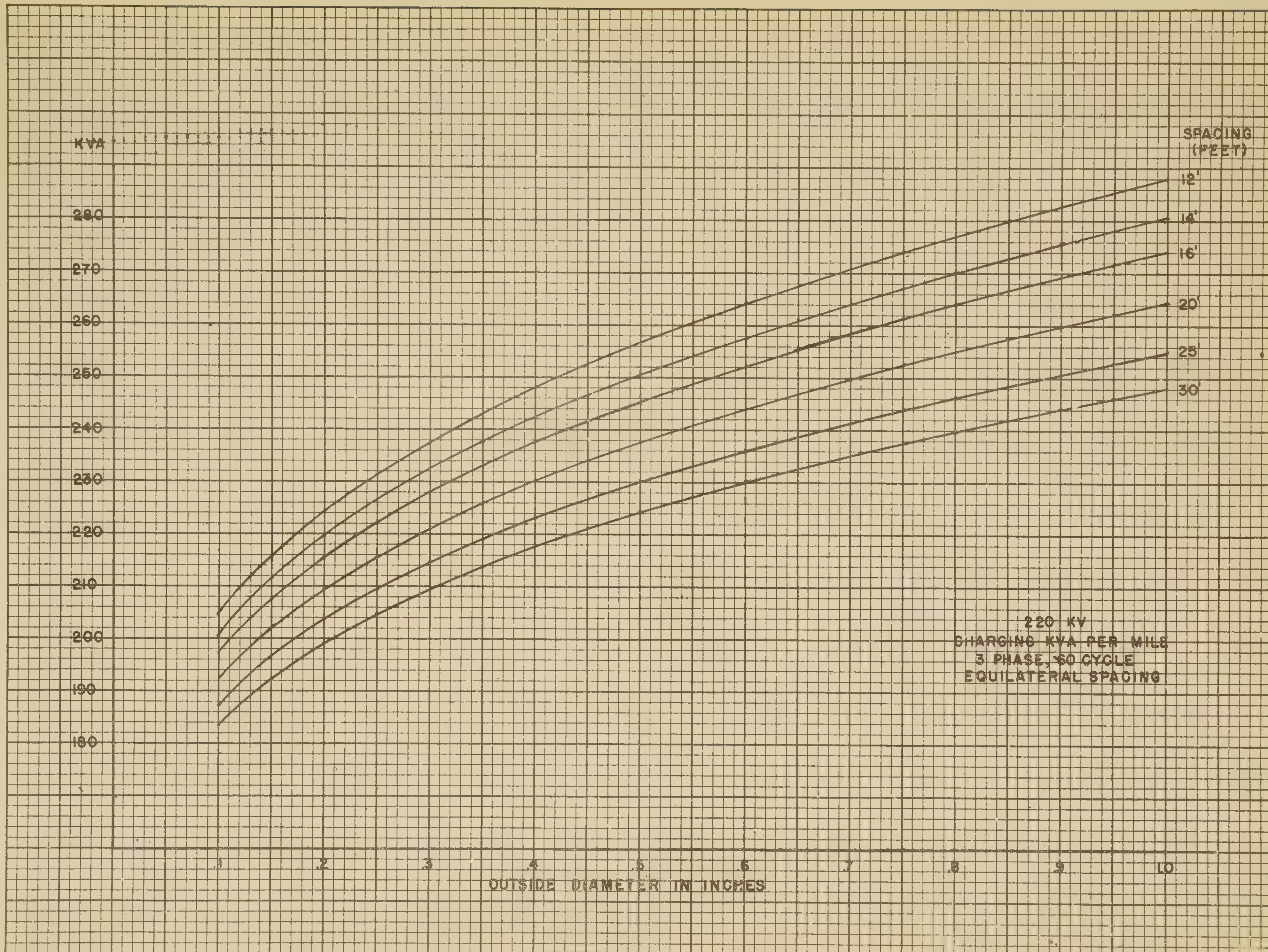


66 KV
CHARGING KVA PER MILE
3 PHASE, 60 CYCLE
EQUILATERAL SPACING
SPACING (FEET)
5'
6'
8'
10'
12'
14'
KVA
31.
30.
29.
28.
27.
26.
25.
24.
23.
22.
21.
20.
19.
18.
OUTSIDE DIAMETER IN INCHES
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0

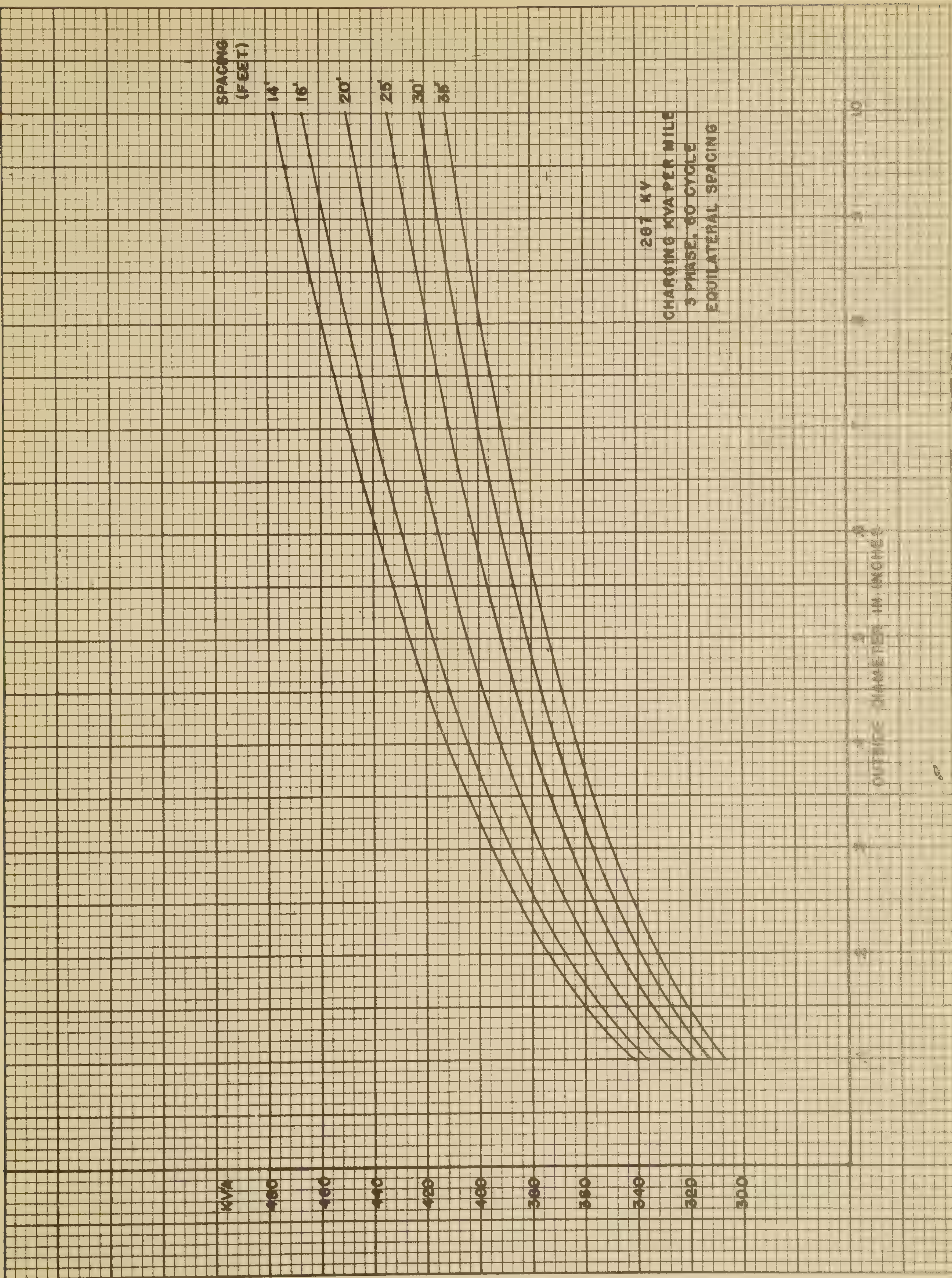

SPACING
(FEET)
6'
8'
10'
12'
14'
16'
20'
110 K V
CHARGING KVA PER MILE
3 PHASE, 60 CYCLE
EQUILATERAL SPACING
KVA
80.
70.
60.
50.
40.
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
OUTSIDE DIAMETER IN INCHES

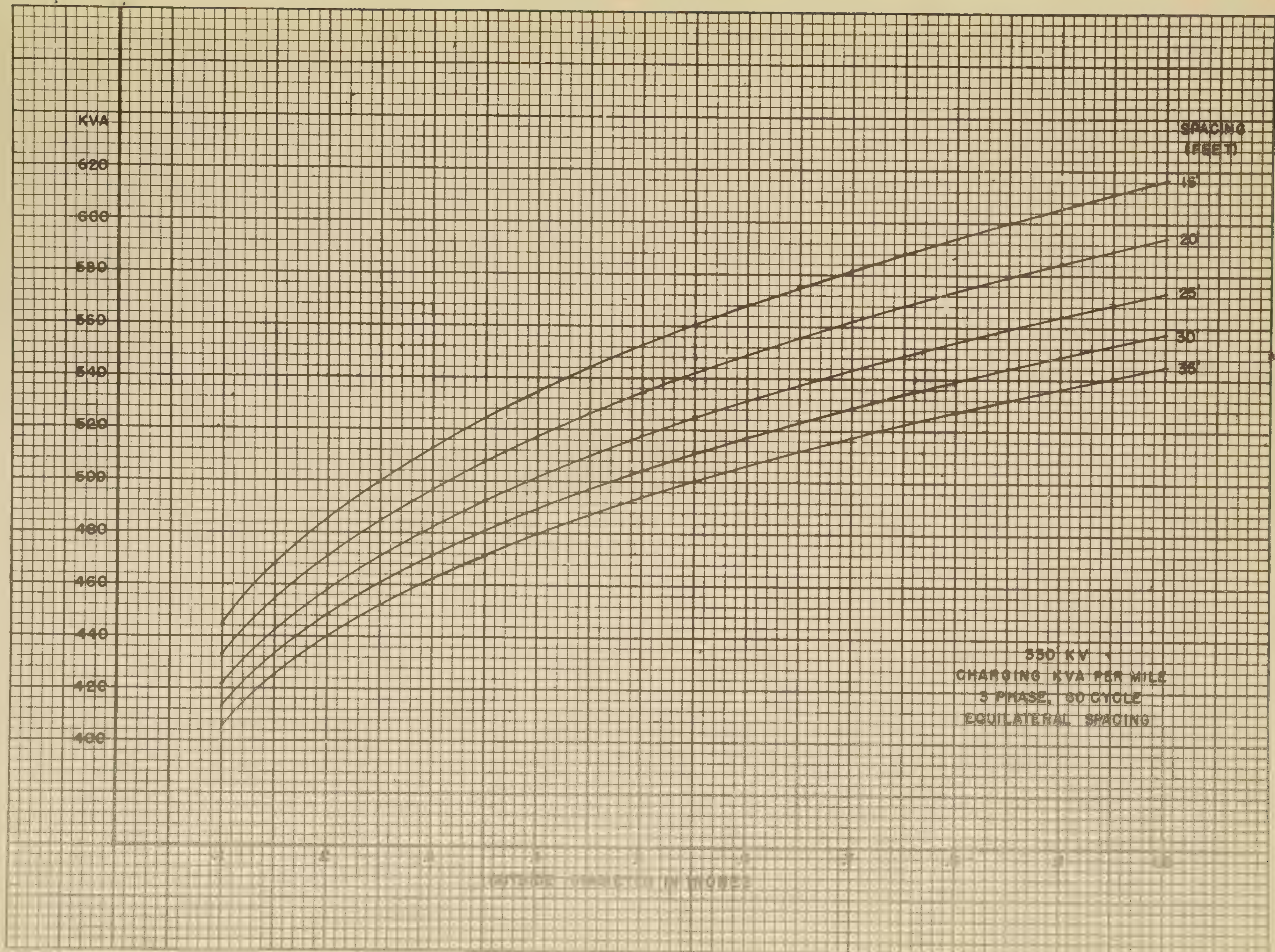

KVA
120
110
100
90
80
70
60
SPACING (FEET)
8'
10'
12'
14'
16'
20'
25'
132 KV
CHARGING KVA PER MILE
3 PHASE, 60 CYCLE
EQUILATERAL SPACING
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
OUTSIDE DIAMETER IN INCHES

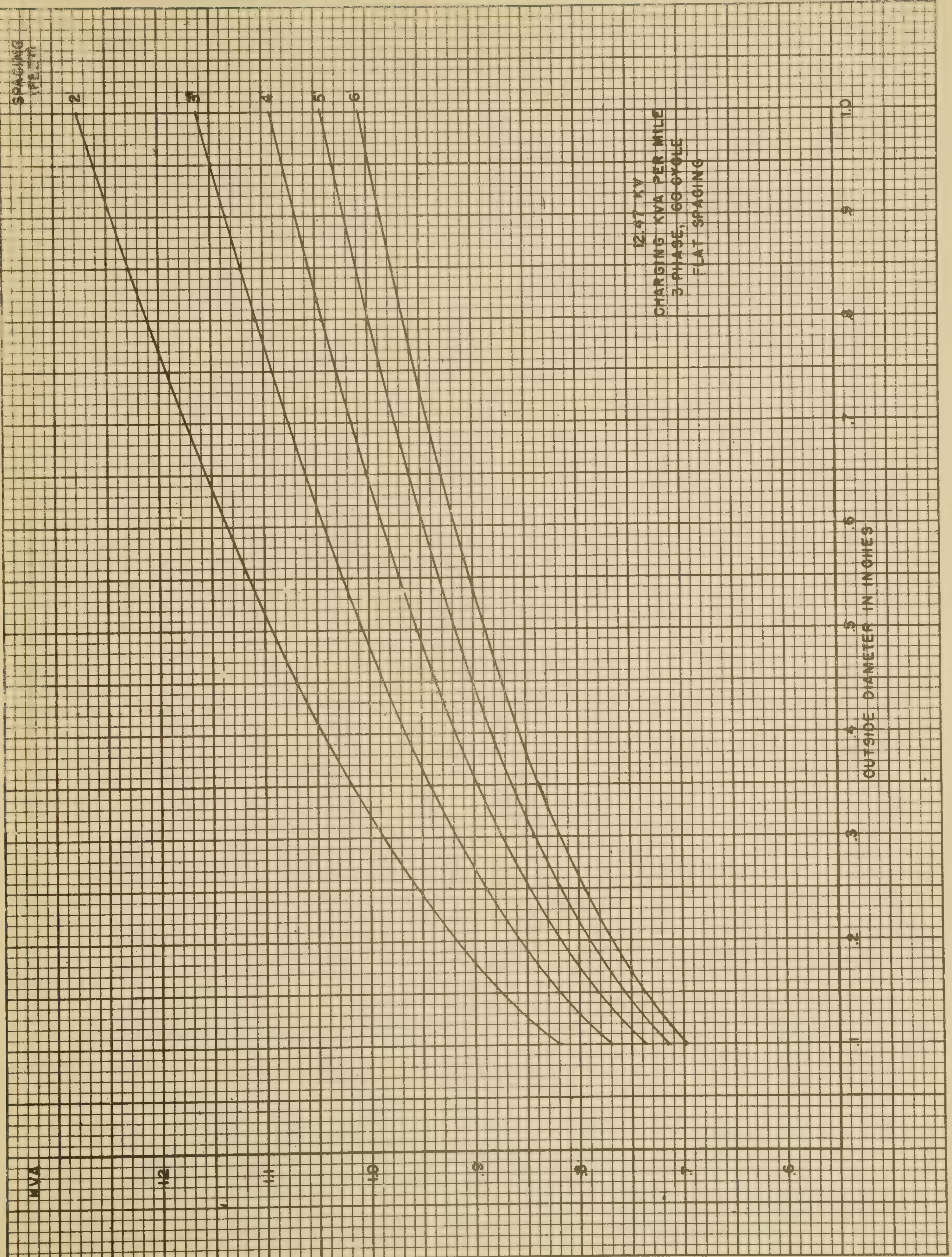

154 KV
CHARGING KVA PER MILE
3 PHASE, 60 CYCLE
EQUILATERAL SPACING
SPACING (FEET)
10'
12'
14'
16'
20'
25'
KVA
150
140
130
120
110
100
90
OUTSIDE DIAMETER IN INCHES
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0



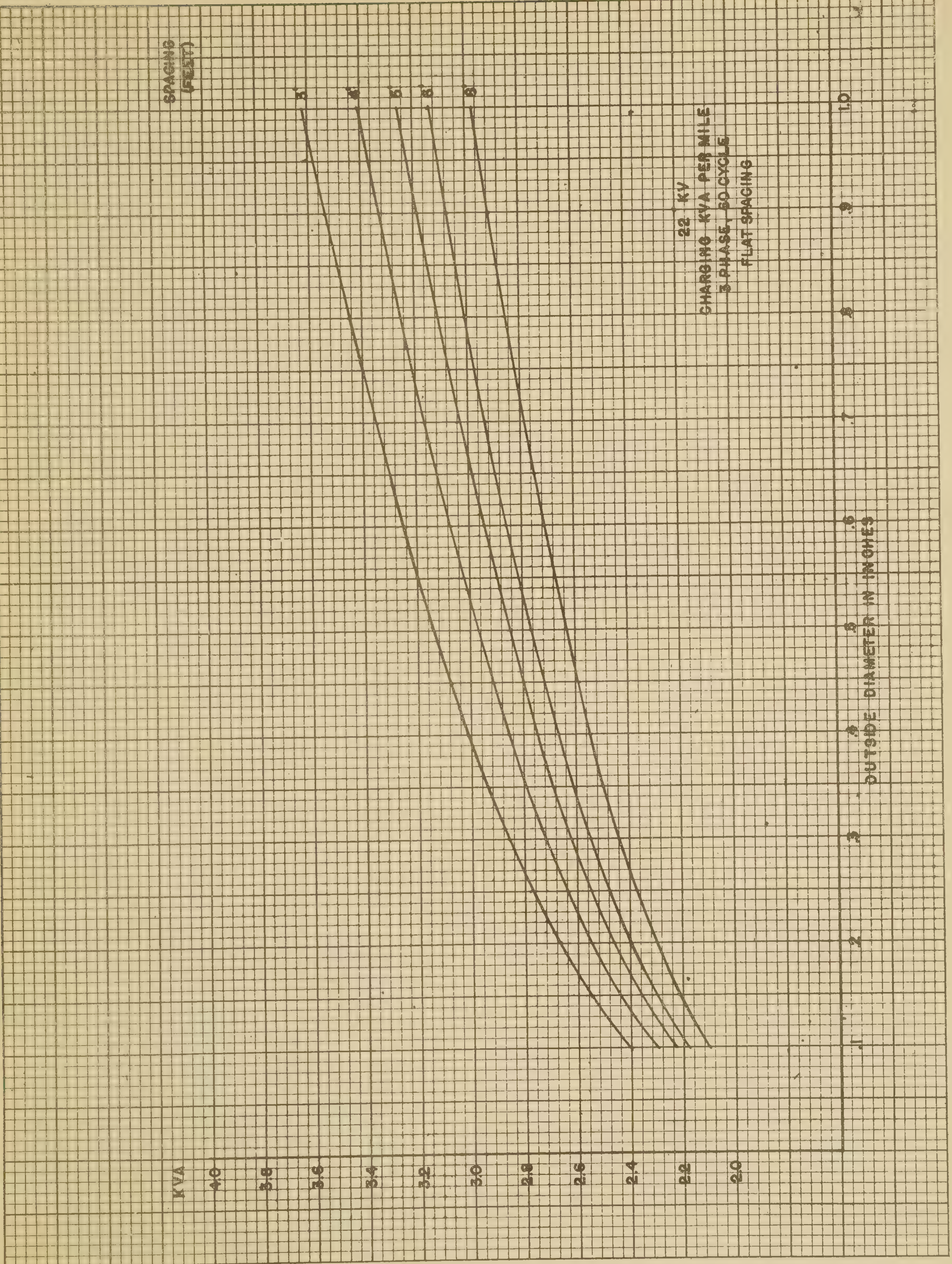
KVA
280
270
260
250
240
230
220
210
200
190
180
SPACING (FEET)
12'
14'
16'
20'
25'
30'
220 KV
CHARGING KVA PER MILE
3 PHASE, 60 CYCLE
EQUILATERAL SPACING
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
OUTSIDE DIAMETER IN INCHES


287 KV
CHARGING KVA PER MILE
3 PHASE, 60 CYCLE
EQUILATERAL SPACING
SPACING (FEET)
14'
16'
20'
25'
30'
35'
KVA
480
460
440
420
400
380
360
340
320
300
OUTSIDE DIAMETER IN INCHES

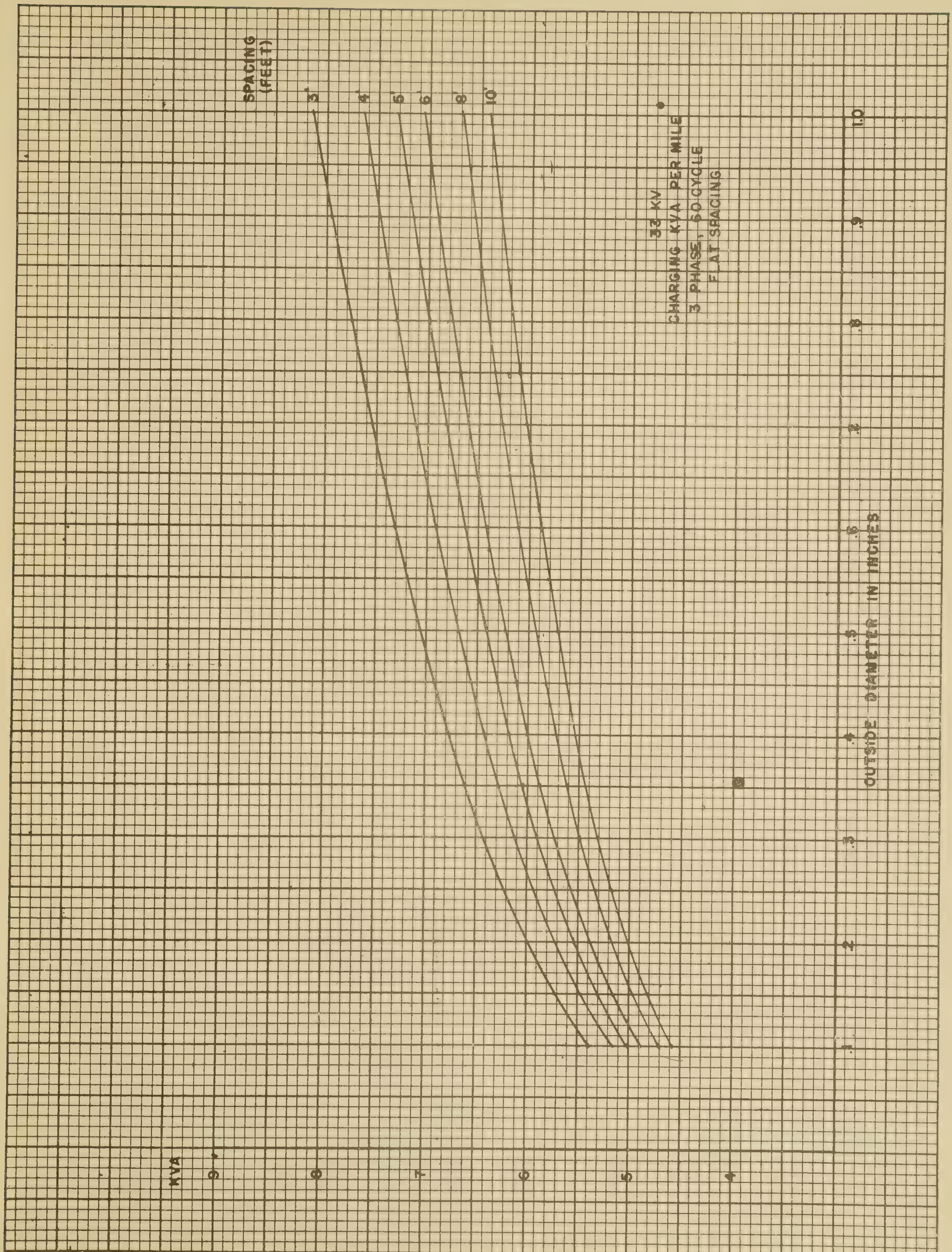

KVA
620
600
580
560
540
520
500
480
460
440
420
400
SPACING
(FEET)
15'
20'
25'
30'
35'
350 KV
CHARGING KVA PER MILE
3 PHASE, 60 CYCLE
EQUILATERAL SPACING

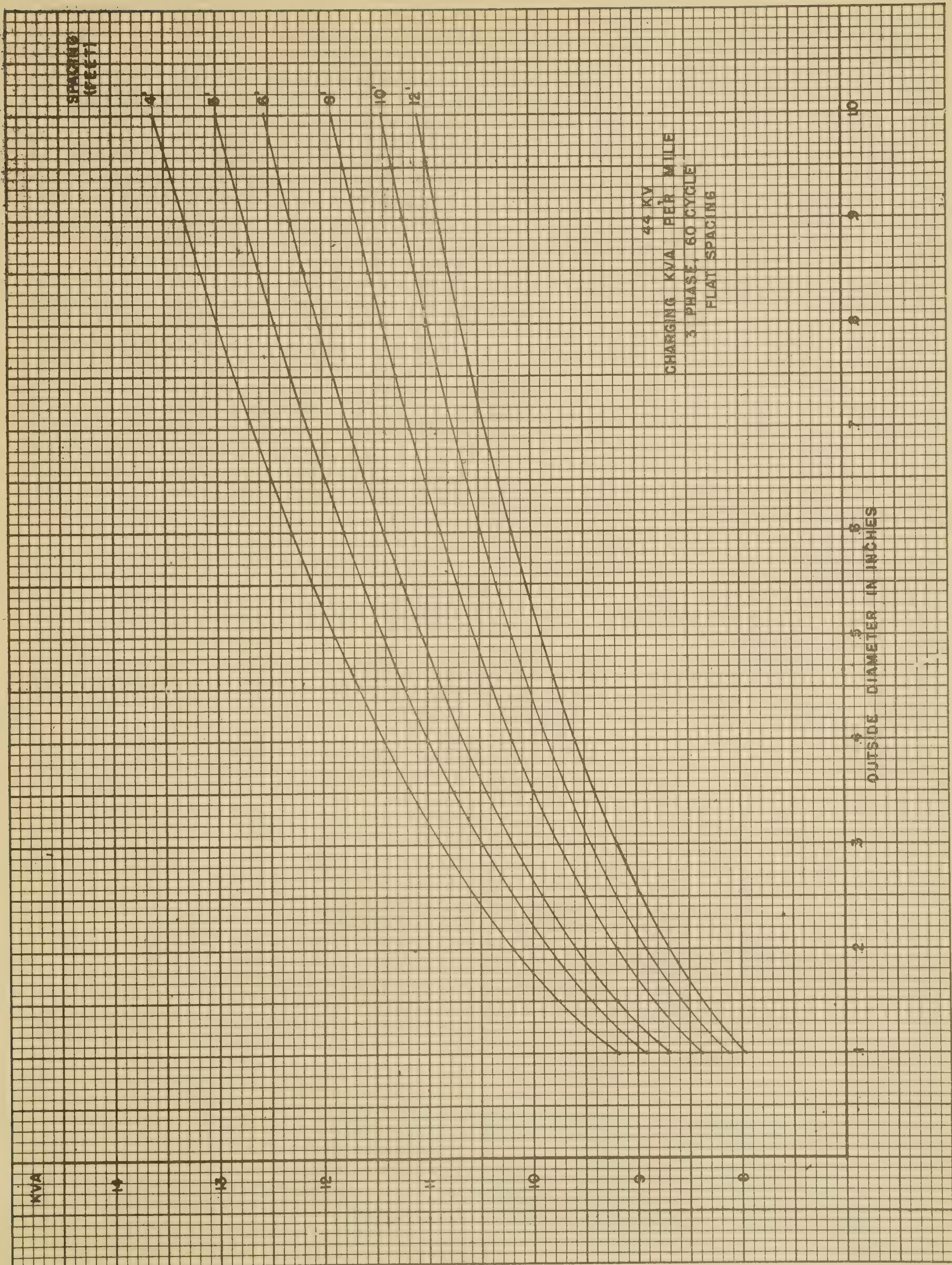


SPACING (FT.)
2
3
4
5
6
12.47 KV
CHARGING KVA PER MILE
3 PHASE, 60 CYCLE
FLAT SPACING
OUTSIDE DIAMETER IN INCHES
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
KVA
1.2
1.1
1.0
.9
.8
.7
.6

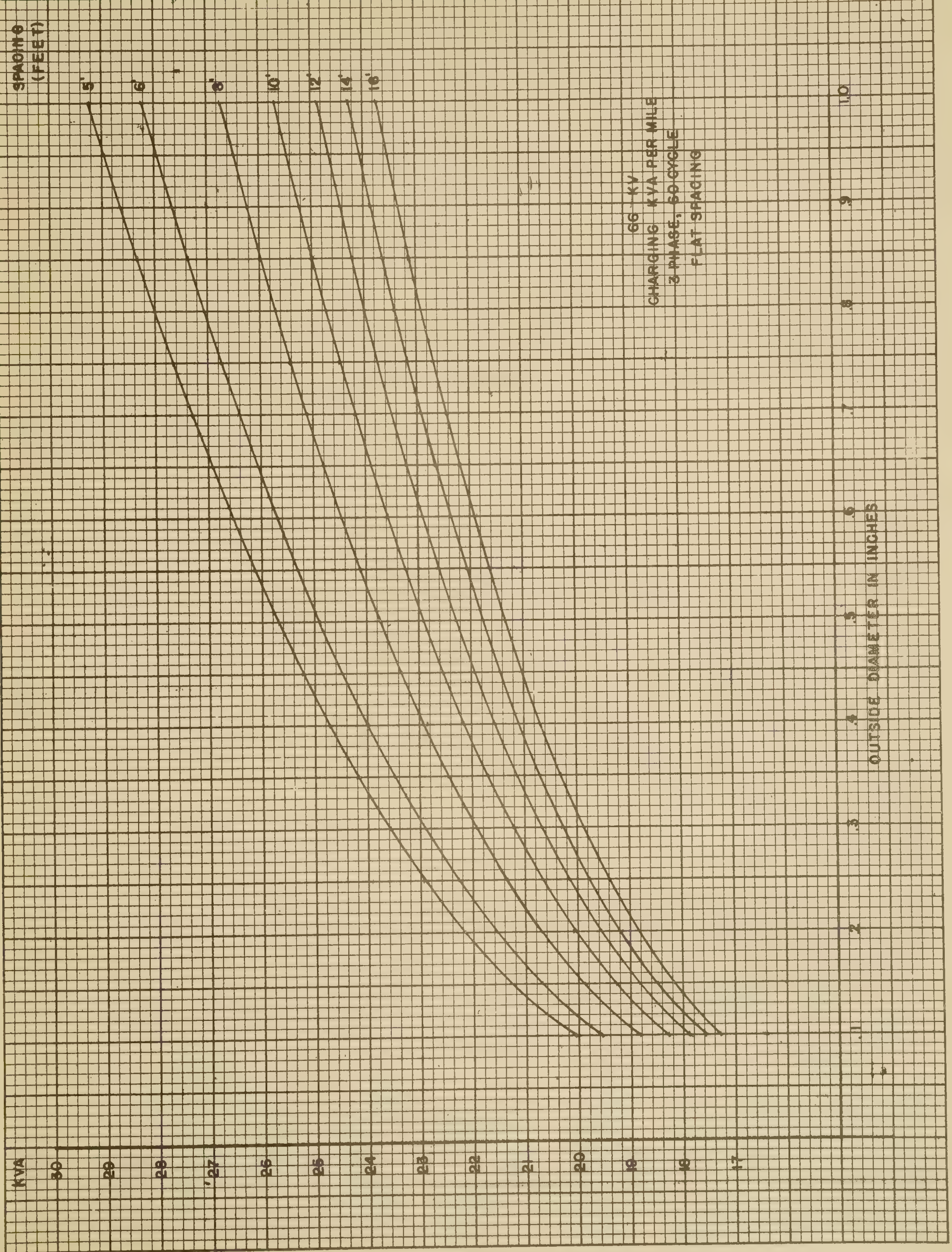


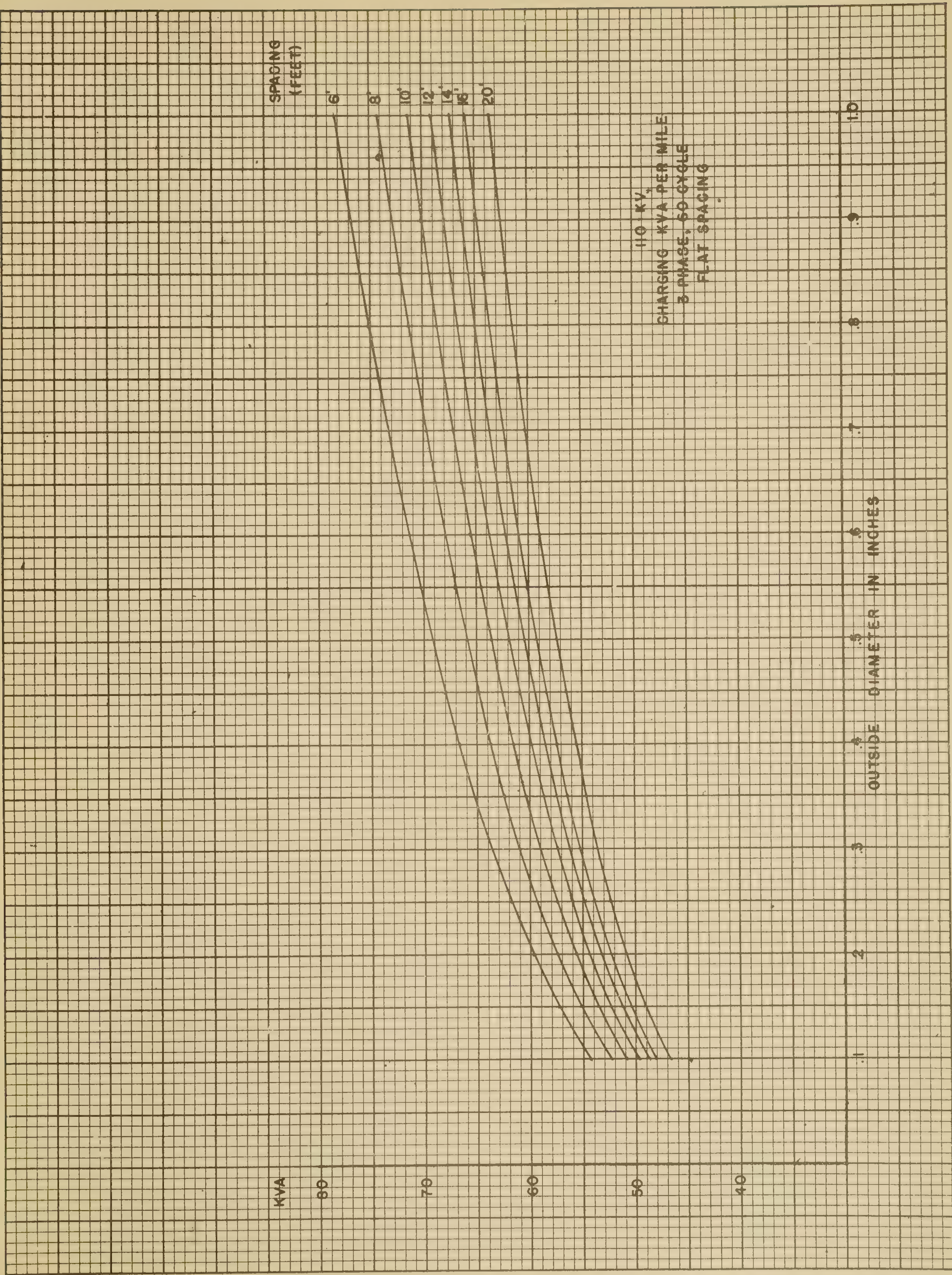
CURVE SHEET NO. 45


33 KV
CHARGING KVA PER MILE
3 PHASE, 60 CYCLE
FLAT SPACING
SPACING (FEET)
3'
4'
5'
6'
8'
10'
OUTSIDE DIAMETER IN INCHES
KVA

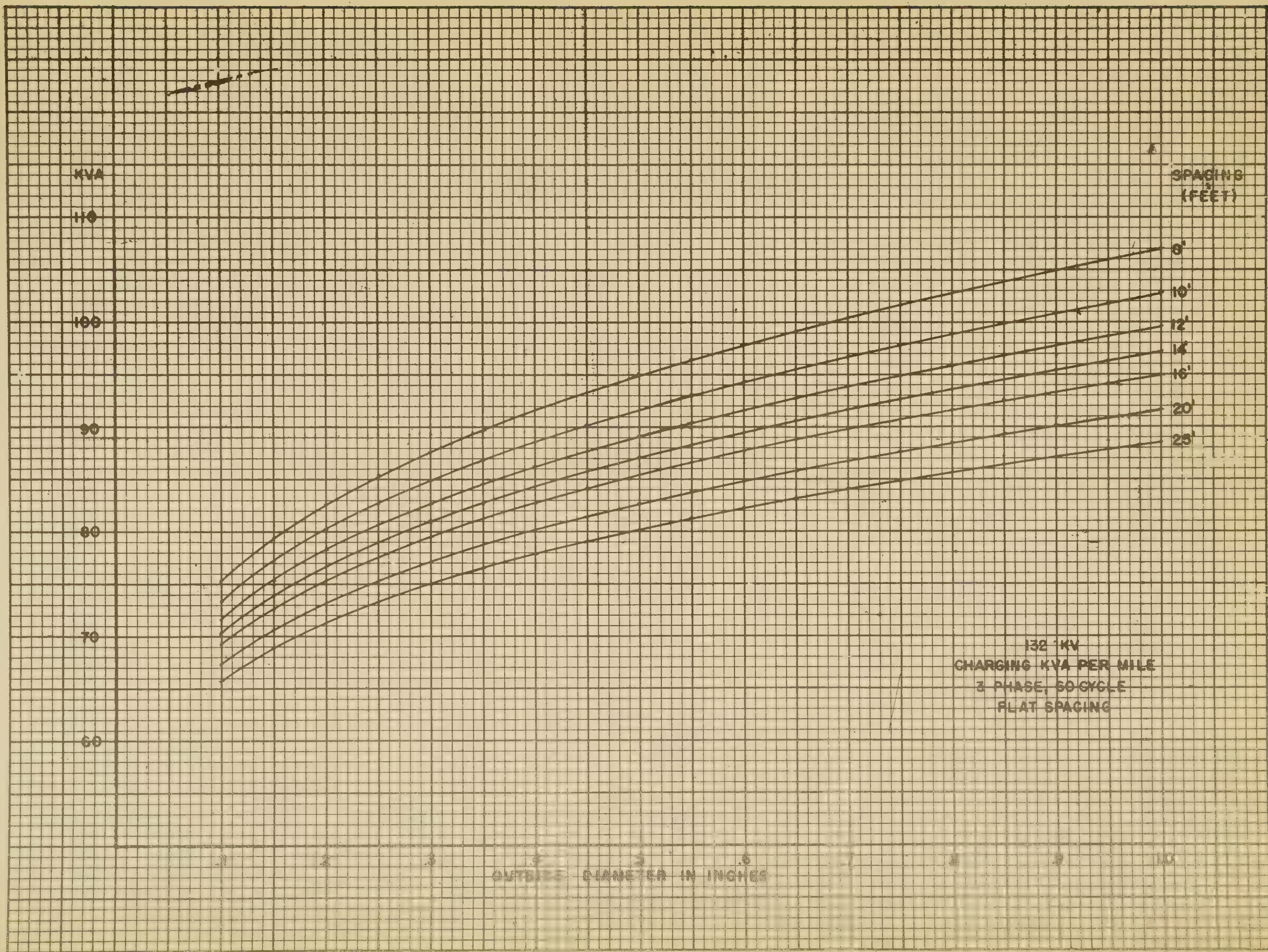


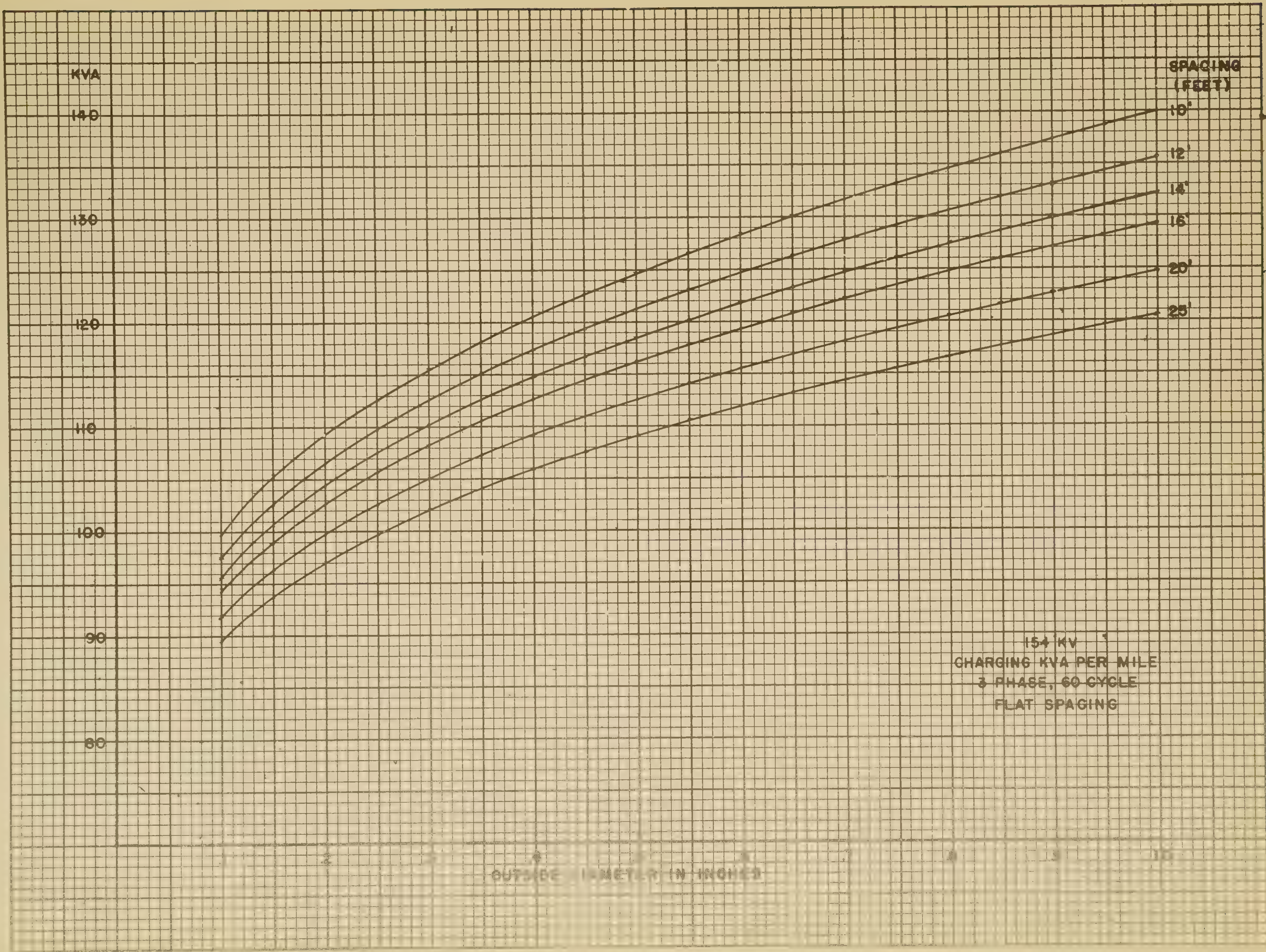
CURVE SHEET NO. 47

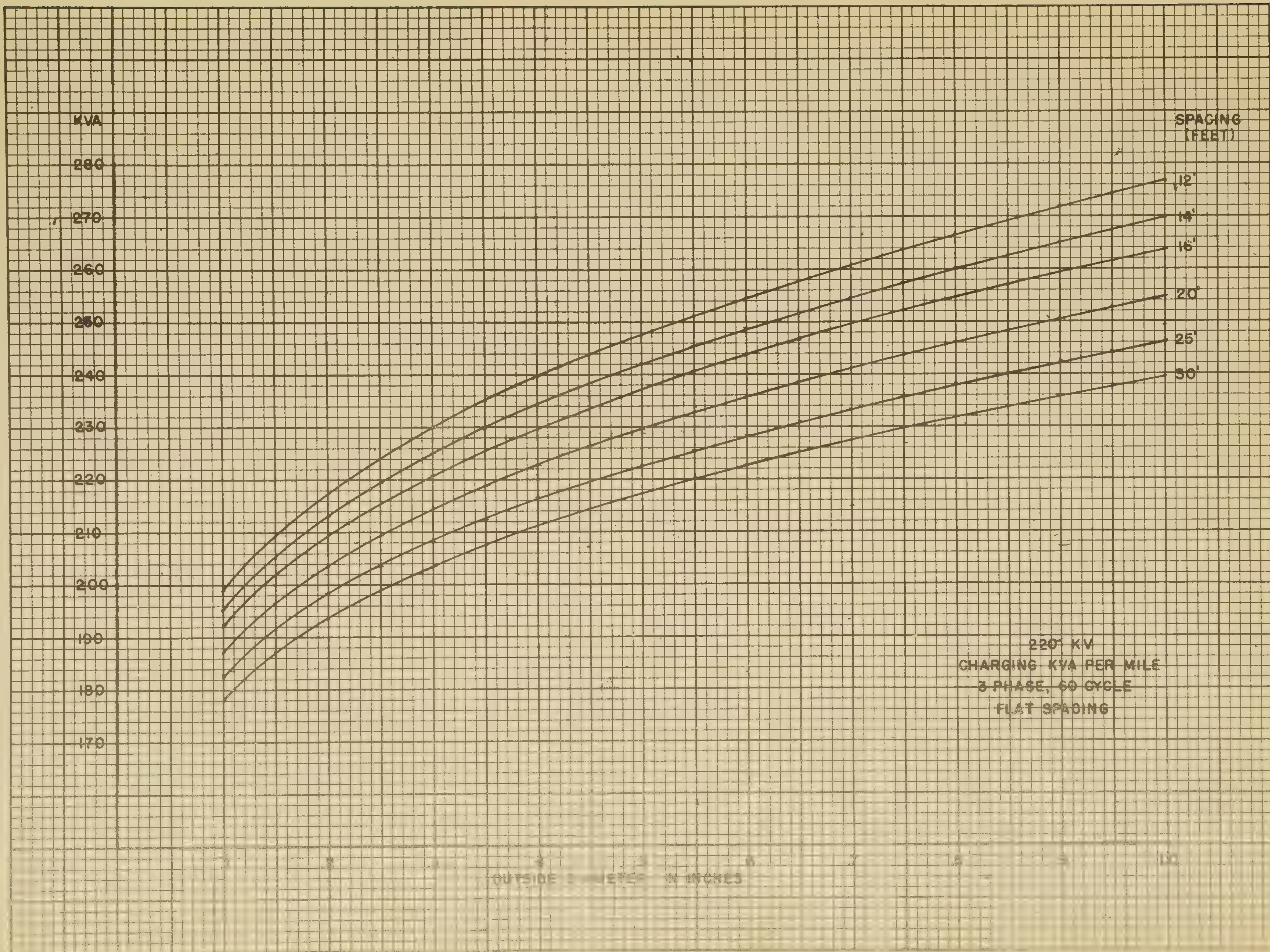

SPACING (FEET)
5'
6'
8'
10'
12'
14'
16'
66 KV
CHARGING KVA PER MILE
3 PHASE, 60 CYCLE
FLAT SPACING
OUTSIDE DIAMETER IN INCHES
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
KVA
30
29
28
27
26
25
24
23
22
21
20
19
18
17

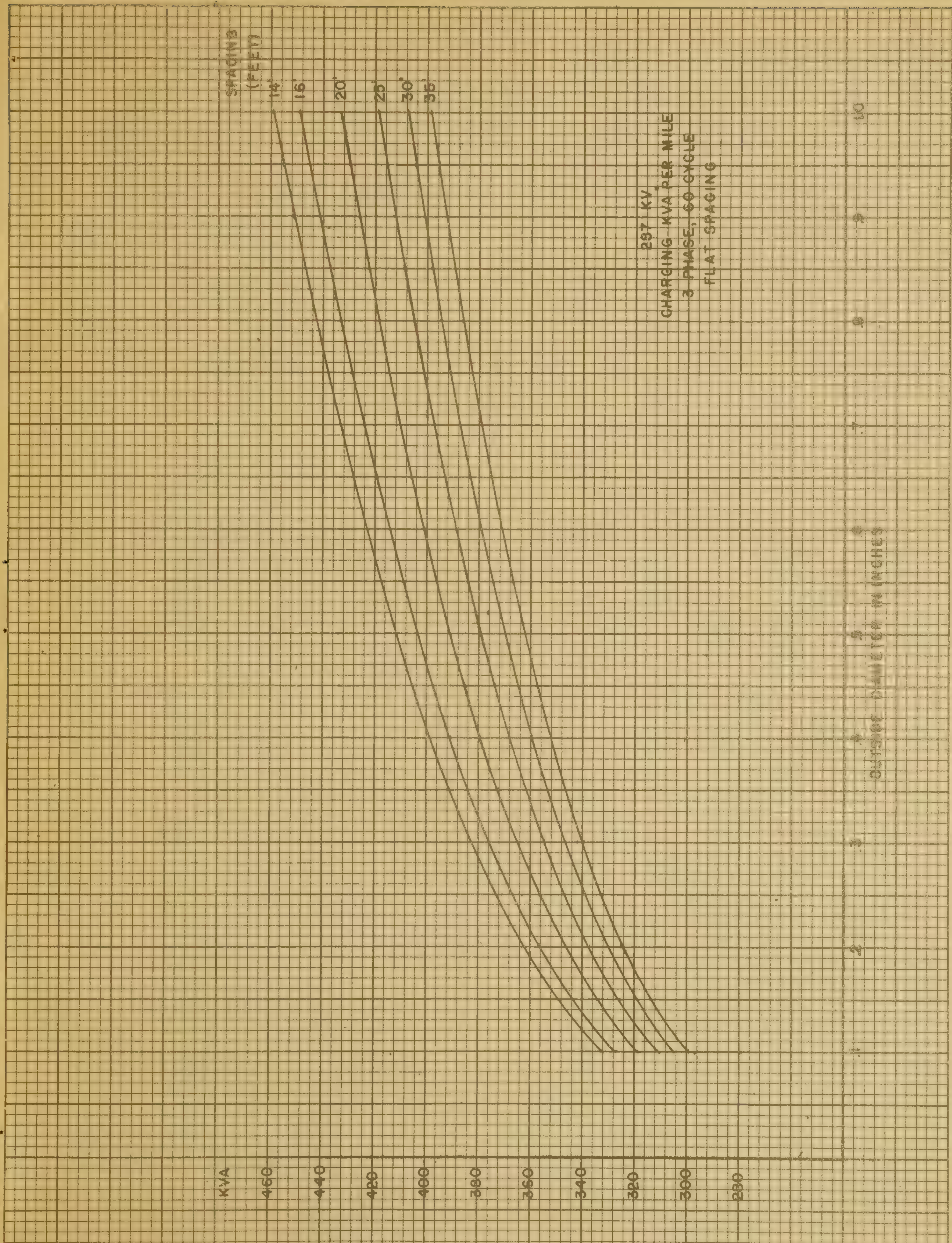


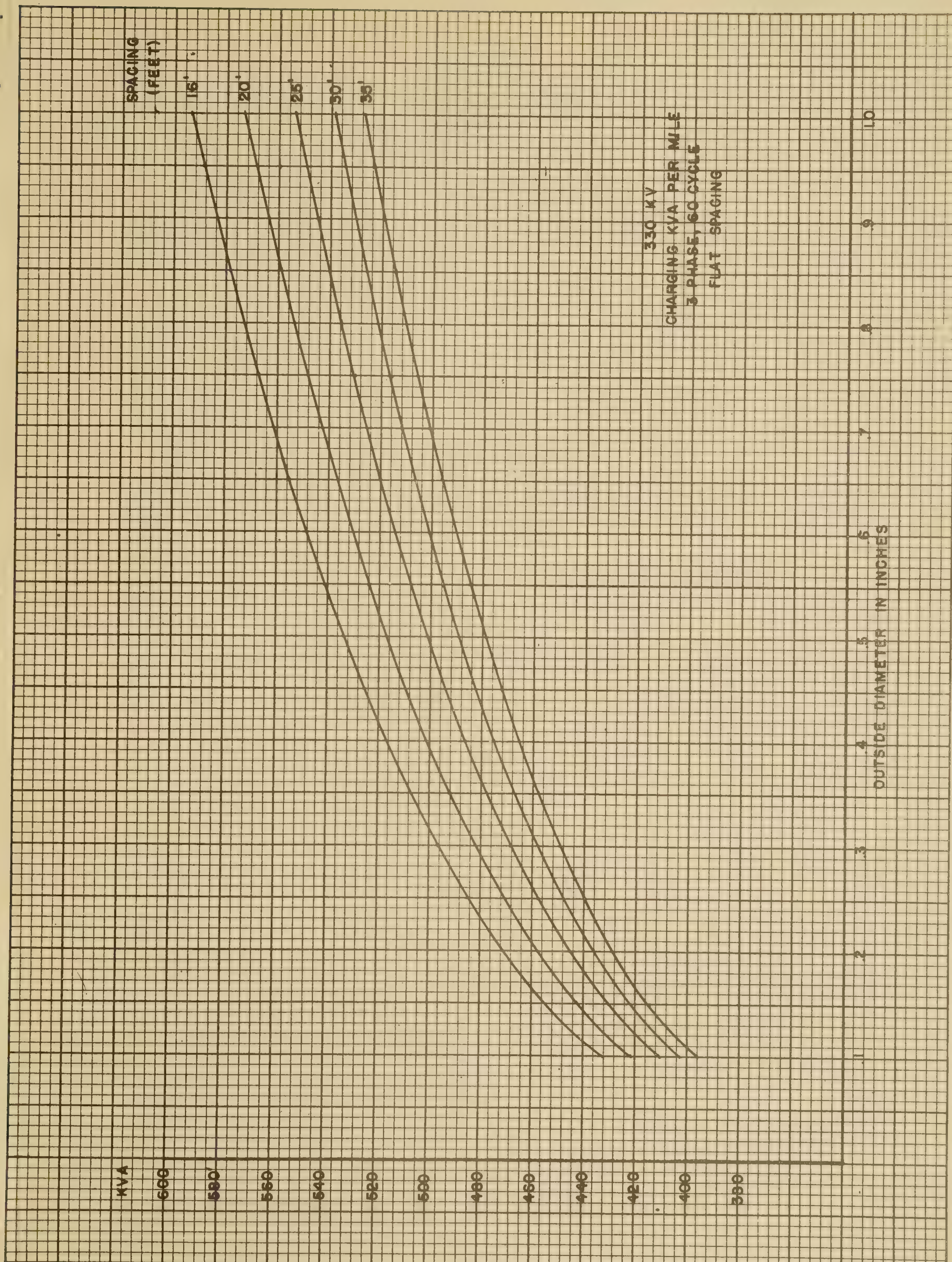
CURVE SHEET NO. 49

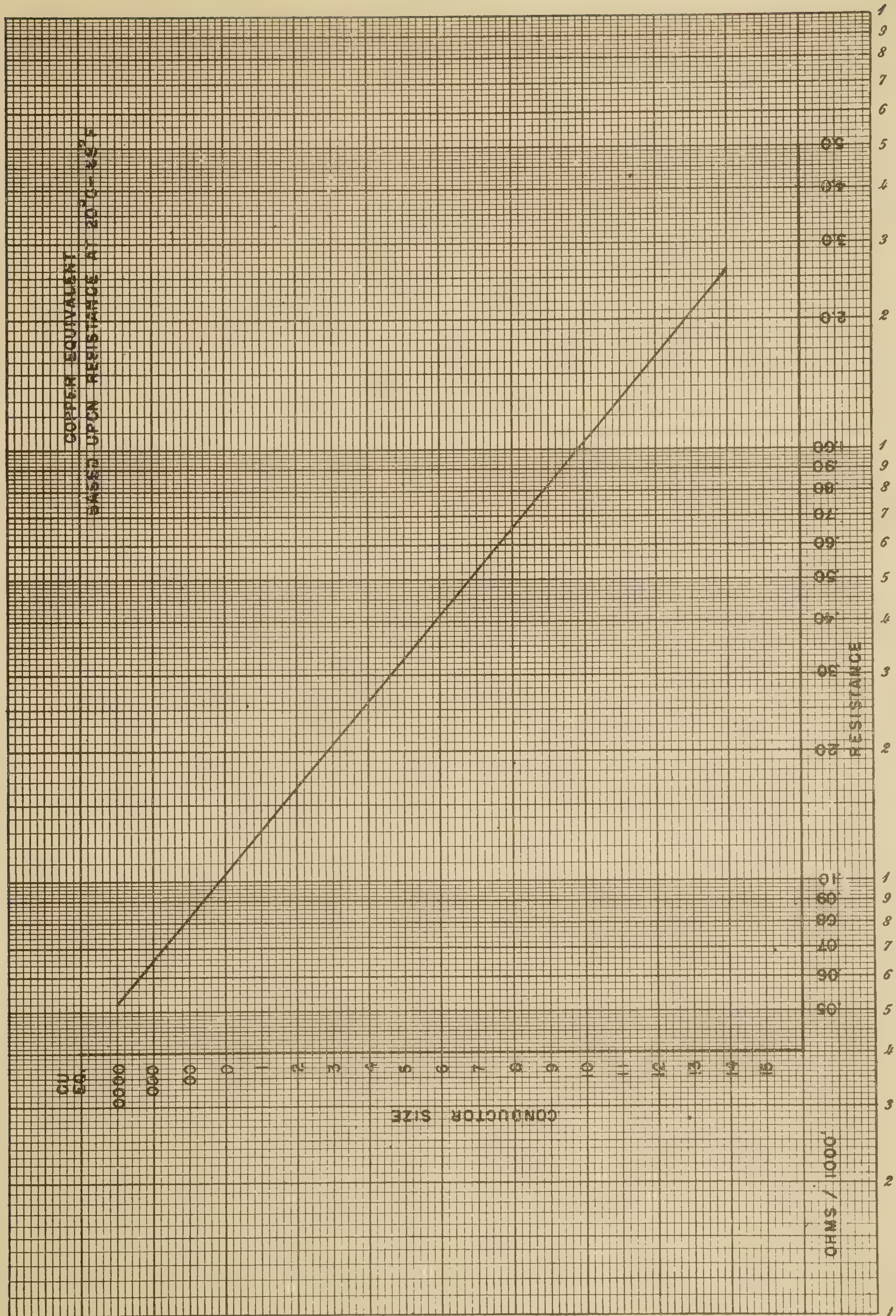

KVA
110
100
90
80
70
60
SPACING (FEET)
8'
10'
12'
14'
16'
20'
25'
132 KV
CHARGING KVA PER MILE
3 PHASE, 60 CYCLE
FLAT SPACING
OUTSIDE DIAMETER IN INCHES


KVA
140
130
120
110
100
90
80
SPACING
(FEET)
10'
12'
14'
16'
20'
25'
154 KV
CHARGING KVA PER MILE
3 PHASE, 60 CYCLE
FLAT SPACING
10
OUTSIDE
IN INCHES


KVA
280
270
260
250
240
230
220
210
200
190
180
170
SPACING
(FEET)
12'
14'
16'
20'
25'
30'
220 KV
CHARGING KVA PER MILE
3 PHASE, 60 CYCLE
FLAT SPACING
OUTSIDE
IN INCHES


SPACING
(FEET)
14'
16'
20'
25'
30'
35'
287 KV
CHARGING KVA PER MILE
3 PHASE, 60 CYCLE
FLAT SPACING
KVA
460
440
420
400
380
360
340
320
300
280
OUTSIDE DIAMETER IN INCHES
1
2
3
4
5
6
7
8
9
10


330 KV
CHARGING KVA PER MILE
3 PHASE, 60 CYCLE
FLAT SPACING
SPACING (FEET)
15'
20'
25'
30'
35'
KVA
600
580
560
540
520
500
480
460
440
420
400
380
OUTSIDE DIAMETER IN INCHES
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0



CURVE SHEET NO. 55

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